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Virginia R. Sturges

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ACTONIAN PRIZE ESSAY.

V. R. Sturges.

CHEMISTRY,

AS EXEMPLIFYING

THE WISDOM AND BENEFICENCE OF GOD.

BY

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TO THE

PRESIDENT, MANAGERS, AND MEMBERS

OF THE

ROYAL INSTITUTION OF GREAT BRITAIN,

This Essay

IS MOST RESPECTFULLY DEDICATED.

PREFACE.

In the year 1838, Mrs. Hannah Acton, widow of the late Samuel Acton, Esq., of Euston Square, from motives of respect and regard for the memory of her deceased husband, and in order to carry into effect his desire and intention, caused an investment to be made of the sum of One Thousand Pounds in the three per cent. Consol. Bank Annuities, in the names of the trustees of the Royal Institution of Great Britain, the interest of which was to be devoted to the formation of a fund, out of which the sum of One Hundred Guineas was to be paid septennially, as a reward or prize to the person, who, in the judgment of the committee of managers for the time being of the Institution, should have been the author of the best essay illustrative of the wisdom and beneficence of the Almighty, in such department of science as the committee of managers should, in their discretion, have selected—the form and conditions of the essay being also, in a great measure, left to the choice of that body.

The subject chosen for the prize of the first period of seven years, was "Chemistry, as exemplifying the wisdom and beneficence of God." The prize was

awarded in April last; and having, on this occasion, had the happiness to be the fortunate candidate, I now beg to offer to the notice of those who feel interested in such matters the essay in question, satisfied that my labour will not have been in vain if the smallest support drawn from the magnificent science of chemistry shall be found to have been given to the Great Argument.

I have to express my great obligations to the Committee of Managers for their kindness in granting me permission to print the work, which has been done without alteration from the original manuscript, the property of the Institution.

Geo. Fownes.

Middlesex Hospital,
May 14, 1844.

INTRODUCTION.

THE study of the structure of the animal frame not only gives proof of the most exquisite mechanical beauty of contrivance in each case, but of the existence of a general plan or type of organization, modified to suit the circumstances of the creature, but always to be traced; further, this general type extends to the animals of the ancient world, whose remains have been preserved in the solid rock.

Comparative anatomy and physiology have contributed, perhaps, more than any other subjects to the argument of foresight, design, and contrivance, in the works of creation. The parallel between the watch and the eye has been extended to many more cases than those originally contemplated. Every microscopical investigation brings to light new instances, each more wonderful than its predecessor. The exact adaptation of the habits, instincts, and appetites of the creature to the circumstances under which it is destined to live; the way in which the individual happiness of the animal, and the permanence of the race, have, by a most elaborate series

of checks and counterpoises, been secured; all have been adduced with the greatest success, as so many proofs of wisdom, design, and benevolence on the part of the great Contriver. These adaptations, it must be remembered, are not merely visible in a few scattered cases; they are universal: they extend to every living creature under heaven.

The higher powers and affections of man have, also, been enlisted in the same great argument. The *necessary* connexion between virtue and happiness, vice and misery—a connexion arising from the very character and configuration of the mind—has been pointed out. The superior permanence and duration of the pleasure arising from the gratification of virtuous and innocent affections above that caused by the exercise of malignant ones, have, likewise, with justice, been insisted upon as proofs of the most satisfactory kind of the benevolence, as well as of the wisdom and power, of the Deity.

Lastly, the physical structure of the earth itself, and the peculiar properties and constitution of the atmosphere, have been minutely described, with reference to the same subject.

The recent discoveries of chemistry, more especially in its relations to animal and vegetable physiology, lead to the hope that it may be possible to draw an inference of design from the chemical constitution of the earth and its inhabitants, hardly inferior in value to that derived from their physical study, although not always so obvious and striking. The following pages contain an attempt of the kind.

The subject will be discussed in the following order :—

THE CHEMICAL HISTORY OF THE EARTH, AND THE ATMOSPHERE.

THE PECULIARITIES WHICH CHARACTERIZE ORGANIC SUBSTANCES GENERALLY.

THE COMPOSITION AND SUSTENANCE OF PLANTS.

THE RELATIONS EXISTING BETWEEN PLANTS AND ANIMALS.

APPENDIX.

ON THE

CHEMICAL NATURE OF THE EARTH AND ITS ATMOSPHERE.

THE researches of modern chemistry have brought to light some fifty-five distinct forms or modifications of matter, each of which must, in relation to the present state of our knowledge, be considered a "simple" or "elementary" substance; the term "undecompounded substance" would, perhaps, be more appropriate and better fitted to convey the idea intended by the chemist. Of these numerous bodies, more than half present that assemblage of characters to which we give the term "metallic;" such as good conducting powers for heat and electricity, brilliant lustre connected with the utmost opacity, and chemical energies directed towards such bodies as oxygen, chlorine, iodine, sulphur, &c. These latter stand at the head of the other division, the non-metallic elements of chemical writers, among which are to be found substances of the very highest degree of importance in the great scheme of Nature, from the universality of their occurrence, and their intimate connexion with

all the phenomena of organic life. It must not be imagined, however, that this division of the known elements into metals and non-metallic substances, is strictly warranted; it is, in fact, more convenient in practice than correct in principle, as a regular gradation from the one class to the other can be easily traced. Antimony, arsenic, phosphorus, selenium, sulphur, constitute such a connecting chain between the two series.

The slightest glance at the general chemical history of our globe will suffice to show the vast inequality in the distribution of these materials. Of the interior of the earth nothing is known; but so far as the surface is concerned—the only part of which man can take cognizance—some eight or ten elements will form the whole list of substances concerned in the formation of the great bulk and mass of all those objects we see around us. The atmosphere is made up of two—namely, oxygen and nitrogen, with, comparatively speaking, mere traces of two others, carbon and hydrogen. Two of these again, oxygen and hydrogen, by their chemical union, give rise to water, occupying in the shape of ocean of unknown depth, lakes and rivers, nearly three-fourths of the surface of our planet: the solid earth we dwell upon is chiefly made up of the oxides of one non-metallic body, silicon, and two metals, aluminium and calcium, the metallic base of lime. Let us add to these, potassium, whose oxide is a constituent of felspar, the characteristic ingredient of granite; sodium, whose great depository is the water of the ocean; and, lastly, iron, whose

oxide is to be found every where to a greater or less extent, and we really include all the known components of our earth, which enter in large quantities into its structure.

Other substances, such as sulphur in the state of gypsum, (sulphate of lime,) and in union with certain metals; magnesium in its oxidized state, and a few more, are found here and there, in local deposits of considerable extent, while the remainder are still more limited in their distribution; and, lastly, a not inconsiderable number of the bodies, recognized as elements, are only to be found in a few minerals so exceedingly rare, that scarcely a sufficient supply of the material can be had for the use of the experimental chemist.

In the organic world the same, or still greater, simplicity is observed; carbon, hydrogen, oxygen, and nitrogen, a little phosphorus and sulphur, and sometimes a small proportion of two or three alkaline and earthy salts, are the sole materials which have been employed in the construction of those countless multitudes of *orders* of living objects which people the earth, and clothe it with beauty.

But, then, this apparent paucity of original materials is more than compensated by the very peculiar properties of some of those selected. The four first mentioned—namely, carbon, hydrogen, oxygen, and nitrogen—are distinguished above all other bodies by the innumerable compounds they are capable of forming, by union among themselves. Modern organic chemistry, vast as it already is, consists of little

more than the study of these four elements and their combinations.

It forms no part of the object of the present treatise to point out to the reader the advantages which mankind derive from the particular mode of structure, or arrangement, of the beds and masses of rock which form the solid earth, made known to us by geology; this has already been done by very able hands. The evident design and contrivance exhibited in the disposition of our mineral treasures is well fitted to excite in the mind the conviction of forethought and provision for man's necessities and comfort. What can be more striking, for example, than the aspect of an English coal-field, where iron-ore of excellent kind lies interstratified with the fuel necessary to reduce it; where the limestone, used as a flux, and even the very grit and fire-clay to build the furnace, are all to be found in one and the same series, often within a few yards of each other. If the ore and the fuel were not thus so curiously related, we should be deprived, by the vastly increased price of the manufactured article, of the power we now enjoy of applying this noblest of all the metals to innumerable purposes of daily life and convenience.

It is not in one particular case alone that this association of iron ore and fuel is observable. The mountains of Sweden and Norway contain inexhaustible beds of magnetic iron-ore; a variety so rich in quality, and so free from deleterious admixture of foreign matter, as to yield, when reduced by

charcoal, the finest and purest bar-iron for making steel, and other purposes where great purity in the metal is desirable. Now the only fuel at all fit for employment in the manufacture of this excellent iron is wood-charcoal, and, accordingly, forests of pines have, by the provident hand of Nature, been planted in these otherwise barren and desolate regions, by the aid of which the iron-maker pursues his labours, thus rendered profitable to the whole community.

This is but a single case out of the many which geology can bring forward as exhibiting prospective contrivance, beneficially exerted, in the structure of the earth; a more minute, and more chemical examination of the subject may, perhaps, even now, in the very imperfect state of our knowledge on many points, tend to strengthen this opinion.

The great mountain-chains which ridge and furrow the earth's surface, and upon whose flanks and lower slopes rest the different stratified aqueous deposites of conglomerate, and slate, and sandstone, and calcareous matter, in all their endless modifications, great part of which have been directly derived from the mechanical degradation of the central mountain-nucleous itself, by the agency of moving water, consist of one and the same material in all parts of the known earth—namely, granite. It is not at random, that this one particular substance has been taken, as a material out of which to construct the great framework or skeleton of our habitation; that, on the contrary, it has been, as it were, deliberately chosen out of many others, so far as their physical properties are concerned, equally good ma-

terials, from a previous precise knowledge of its peculiar chemical fitness for the office in question; and this it is not very difficult to show, so far as such a thing can be shown.

One of the most obviously indispensable conditions of all animal existence is a supply of food; this supply must, it is equally clear, be derived, either directly from the vegetable kingdom, or indirectly, in the case of the carnivorous races, whose nutriment is drawn from the flesh of plant-eating animals: animal life, therefore, necessarily presupposes vegetation, and is regulated in its extent by the luxuriance or deficiency of the latter. Now all plants, as will hereafter be noticed, derive, in the first instance, the whole of their "organic constituents" (by which term the elements carbon, hydrogen, oxygen, and nitrogen, are signified) from the atmosphere which bathes their foliage, and from the rain-water which is absorbed by their roots. Plants, however, contain in every case, without a single exception, other substances besides the four mentioned, although in very much smaller proportion, but which cannot be looked upon as accidental, since experience has shown them to be quite indispensable to vegetable life; moreover, the constancy of their occurrence, and their different nature in different plants, and even in different parts of the same plant, all point to this conclusion. Such bodies are the alkalis, potash, and soda, phosphoric and sulphuric acids, lime and magnesia, silica, and, perhaps, a few others; these form the contingent of food really furnished by the soil in which the plant grows, and are

each in its turn as necessary to its well-being as the carbonic acid, or the water it gets from the air.

Of these inorganic principles, one of the most indispensable of all to land-vegetation, with which we are principally concerned, is potash; there is not a single vegetable in the field or the wood, the ashes of which does not contain this substance in one state of combination or another, and often in very large quantity, so much so, that an idea was once held that plants possessed the power of generating the substance within themselves; an opinion which more careful inquiry has negatived, by showing the real source of the alkali, and the state in which it exists in the soil.

Another, perhaps equally important substance, is phosphoric acid, a body as universally diffused in the vegetable kingdom as potash itself; not a plant can be found from which phosphates are absent. Indeed it is easy to see the reason of this provision, if the important function fulfilled by one of the earthy phosphates in the animal economy be considered for a moment: it is phosphate of lime which gives strength and stiffness to the bony framework of the animal body, and which salt must be furnished by the food the creature subsists upon. Taking into account, therefore, the fact that there is scarcely a green plant which does not furnish support to one or other of the vegetable feeders among the higher orders of the animal kingdom, it is easy to see the reason why of set purpose such a relation should have been established between the ultimate function and office of the plant—namely, the main-

tenance of sentient life, and a condition indispensable to the growth of the plant itself. Suffice it to say, as the result of exact experimental investigation, that without potash and phosphoric acid vegetable life cannot go on, much less flourish.

Now let us inquire for a moment what sources of these two substances we possess in the solid earth itself; both are now, in the advanced state of analysis, easily discovered when sought for by appropriate means. We find, on making the investigation, that hardly a rocky bed can be examined without both coming to light—often mere traces, it is true, but still they are present. Here, however, a difficulty occurs, at least with one of them; with the exception of a very small group of the oldest sedimentary rocks, every stratum, almost without exception, from the tertiary formations to the ancient slate, contains embedded the remains of formerly existing races of animals. The shells and bones of those creatures contain phosphate of lime, which thus becomes a constituent part of the rock itself; and from the comminuted state in which these remains are often found, it may easily happen, that the salt may be discovered in portions of the bed where no organic remains are perceptible to the eye, and yet be really derived from this source alone.

Dr. Schweitzer, of Brighton, in an analysis of the chalk rock of that neighbourhood, made some little time ago, discovered a notable quantity of phosphate of lime, and attributed it, with great show of justice,

to an admixture of the shells of crustaceous animals in a finely divided state, which have thus become part and parcel of the present chalk bed.

Whence, however, it may be asked, did these animals get this acid component of the shelly coverings; whence the phosphate of the ichthyosaurus rock and the coprolites of the Dorsetshire lias, unless phosphoric acid formed a specific ingredient of the ancient unorganized earth, provided ages before the first indication of organic life at all? Phosphorus is an elementary substance; there is not a tittle of evidence in favour of its generation by living beings of any kind; it becomes, therefore, highly desirable to be able to point out its original place among the components of the primordial earth.

Now there is every reason to think that this place is to be found in the ancient massive granite, before spoken of as forming the basis and foundation of our present system of continents. It is true that phosphoric acid has not been directly found, to my knowledge, in this situation, in either the felspar or the mica of this rock; but then phosphoric acid in union with alumina, as it may be expected to be in these cases, is a substance particularly easy to overlook in analytical inquiries, as almost every chemist knows to his annoyance, and it is not at all unlikely that proper and diligent search would be rewarded with success.

There are many circumstances which tend to point out phosphoric acid as an original constituent of one or more granite minerals. Crystallized phos-

phate of lime is not unfrequently found lining the sides of small cavities in this rock; a massive variety occurs in some abundance in more than one primary district; phosphate of lead is found in some of the Cornish mines; phosphate of alumina, in a crystallized condition, is met with in an ancient slate deposit; and many other cases might be cited in evidence of the presence of phosphorus in the old crystalline igneous rock.*

The theory of the origin of potash from the same source is in the highest degree satisfactory. It is well known that felspar forms four-fifths, at least, of all ordinary granite; and further, that this mineral contains beween fourteen and fifteen per cent. of potash. It is, in fact, a true saline combination, a double silicate of alumina and that alkaline base, corresponding to common alum, only having silicic acid in place of sulphuric. It is also generally remarked that this felspar is subject to decomposition by the agency of the weather, and chemical examination has made pretty clear the general nature of the change. It is, in fact, a case in which an insoluble saline substance is slowly decomposed by contact with water—a circumstance by no means

* Since the above was written, the author has succeeded in finding phosphoric acid in considerable quantity in the porcelain clay of Cornwall, and in the decomposed granite by which it is furnished. The same substance was also found in several specimens of lava from different localities. The felspar of sound unaltered granite yielded but indistinct indications of phosphoric acid, which may probably be ascribed to the greater difficulty of the investigation.—See Appendix, No. I.

uncommon; potash, retaining some silica, is dissolved out; silicate of alumina, with the residue of the silicate of potash, remains behind; this still slowly undergoes decomposition in the same way, until at length little else remains but silicate of alumina, or "clay," the form and appearance of the original felspar being utterly lost. This ultimate change, however, is a very slow one indeed; ages and ages elapse before all the alkali is extracted from the aluminous portion, from the compact and insoluble state in which it existed in the felspar.

These remarks will suffice to render, to a certain extent, intelligible the fact of the constant presence of potash in every fertile soil that has been examined,—that is, every soil containing a due proportion of clay, the product, either immediate or remote, of the decomposition of a felspathic rock. This potash in the soil is in an insoluble form, not to be extracted by mere treatment with water; it is only to be discovered by a regular analysis, in which the finer part of the soil, deprived of its organic matter, is decomposed at a white heat by carbonate of baryta, or lime, or when it is acted upon for some hours with boiling oil of vitriol. In this insoluble state, it resists the solvent power of the rain water, which would otherwise carry it away and reduce the land to barrenness in a few years, and is only set free, little by little, by the long-continued contact of that liquid, aided by the alternations of frost and heat, in just sufficient quantity for the use of plants growing in the soil, whose rootlets then absorb it with facility.

It is not, then, by blind chance that granite occu-

pies so important a place in the framework of our earth ; indeed it may be said of rocks of igneous origin generally, both ancient and modern, that they are the natural depositories of the alkalies, which, by their slow disintegration, become liberated, and contribute to spread fertility and abundance over the face of the globe, and perhaps to perform other functions of not less importance, when they at length reach their last resting-place, the great ocean.

The whole subject of the formation of cultivable soils, and their distribution over the earth's surface, is replete with interest and instruction. Every earthquake which has, in by-gone times, fractured and dislocated the solid strata, every flood which has swept over the ancient continents, every change of level which has elevated the bed of the ocean or depressed the land beneath its surface, has contributed, more or less, to bring about that mixture of materials—sand, clay, and calcareous matters—which now form the earth's upper covering—the fruit-bearing soil, the inexhaustible source of prosperity and strength. Surely, it is not too much to infer that all these things had reference to that future condition of the earth, when it should become the habitation of beings capable of appreciating the wonders around them, and deriving mental support and guidance from the contemplation of these wonderful p ovisions, while enjoying with thankfulness the physical comforts to which they give rise.

The saltness of the ocean has usually been regarded as a special provision of nature to guard against certain inconveniences which might otherwise have

resulted. The presence of so much saline matter in solution depresses the freezing point of the water many degrees, thereby diminishing the dangerous facility with which fields of ice are produced in the polar regions. It has been said, also, that the salt is useful in checking evaporation, and also that it aids in preventing the corruption of the water by the accumulation of animal and vegetable remains. Without for a moment questioning the incidental benefits resulting from the circumstances under discussion, and which, in one case at least, are quite obvious, it may be suggested that the saltness of the sea may be considered rather an inevitable result of the present disposition of things, than a special arrangement expressly intended to fulfil certain particular objects.

The rain which falls upon the earth is due to the condensation of aqueous vapour previously existing in the atmosphere, and which is supplied in great part by evaporation from the surface of the sea—the area of the latter compared with that of the land being very great, necessarily so perhaps, to furnish the requisite extent of evaporating surface. This water is, as is well known, perfectly fresh and pure, the saline constituents of the ocean having no sensible degree of volatility at the temperature at which the vapour has been raised. No sooner, however, does it reach the earth than it becomes contaminated with soluble substances which it meets while flowing on the surface of the ground or percolating beneath. It is thus that the waters of springs and rivers invariably contain a greater or less amount of alkaline

and earthy salts, which all eventually find the way into the sea, and there remain, since there is no channel for their return. The saline condition of sea-water is but an exaggeration of that of ordinary lakes, and rivers, and springs; the materials are the same, and of necessity so; the ocean being, in fact, the great depository of all the soluble substances which, during innumerable ages, have been separated by a process of washing from the land. The case of the sea is but a magnified representation of what occurs in every lake into which rivers flow, but from which there is no outlet except by evaporation. Such a lake is invariably a salt lake. It is impossible that it can be otherwise; and it is curious to observe that this condition disappears, when an artificial outlet is provided for the waters. It will be remembered that the saltness of the ocean is very far exceeded by that of several inland lakes of the kind described. That of Aral near the Caspian, and the Dead Sea in Judea, are remarkable examples.

The nature of the substances thus extracted from the bosom of the earth, and carried seaward, deserves attention. The most abundant of all is usually common salt; next, certain combinations of magnesia; then, salts of lime, the carbonate held in solution by excess of carbonic acid, the sulphate, perhaps, in addition; and, lastly, comparatively small proportions of potash and oxide of iron, with mere traces of bromides and iodides. The occasional occurrence of large proportions of the last-named bodies in the springs of a few districts is a

phenomenon dependent upon local causes,—no doubt the peculiar nature of the rock through which the water rises.

Such are the foreign substances diffused in greater or less proportion in all the waters we employ for the various purposes of life, and which are accumulated, or concentrated, as it were, in that of the sea to a far greater extent.

Some of these principles possess, however, obvious and palpable uses when thus dissolved. It is highly probable that the iodine of sea-water is connected in some way with the well-being of submarine vegetation; that it forms an indispensable component of the food of these plants. It is difficult to account on any supposition for its constant occurrence in certain of them. They appear to have the power of seeking out and appropriating to themselves the almost infinitesimal quantity of iodine which analysis indicates in sea-water. Again, the lime-salts have their use, and a most important one it is. Shell-fish and coral polyps depend upon them for the material of their curious structures. The geologist and the navigator will readily appreciate the extent to which the surface of the globe has been altered and modified both in ancient and modern times by the silent labours of myriads of these creatures, all engaged in the production of calcareous matter. The limestones of this and other countries are often visibly made up of the relics of these animals; and even when, from comminution, these cease to be apparent to the eye, the microscope yet discovers them. It may even be

that *all* limestones, with some trifling exceptions, are of animal origin; and that when organic remains are not found, the r ason is to be sought in their obliteration by partial fusion.

It is very possible, also, that what we are accustomed to call impurities in ordinary water may be of great service to the living system. These matters are admitted to exercise an influence upon the body in particular states of disease; and if so, it is unlikely that they should be altogether inactive in health. Pure distilled water, even after long exposure to the air, is exceedingly vapid and disagreeable to the taste, which may be taken as a sort of indication of its unfitness for ordinary use.

A review of the properties of the different compounds of the rarer elementary bodies—rare in the sense already adverted to—will serve to show that their action upon the animal system is almost invariably prejudicial, and often highly poisonous even in small quantities. Among the metals, for example, almost the only one, the oxide of which is harmless to the living body, is the metal iron. If the oxides of copper or of lead were as widely diffused as this substance, the result would be most disastrous. The daily absorption into the system of minute quantities of metallic poisons is known to be followed by consequences of a fearful kind. Too many such cases are unfortunately on record. Had carbonate of baryta been as abundant as carbonate of lime, animated life would, in all probability, have failed before its deadly influence. It is difficult to avoid the conclusion that the arrangements described have

been made with special reference to the properties of the bodies employed, and that an intelligent choice has really been exercised in their selection.

Let us now turn for a moment to the chemical study of the atmosphere. The plan of the present work renders it unnecessary to discuss the experimental evidence of the composition of the air. Suffice it to say, that in the atmosphere can be detected at least four distinct elementary substances—namely, oxygen, nitrogen, hydrogen, and carbon. The mode in which these are arranged is as follows: the great bulk of the air is made up of a mixture of oxygen and nitrogen gases in the proportion of twenty-one measures of the former to seventy-nine of the latter. The two gases are in a state of mere mechanical mixture, not chemically combined. In addition to these, are to be found a little carbonic acid gas, usually about $\frac{1}{2000}$th part by measure of the whole, but subject to occasional slight variation; a quantity of vapour of water, depending very much upon the temperature; and, lastly, a just distinguishable trace of carbonate of ammonia. These are the only substances yet demonstrated to exist in air collected in the open country at a distance from towns.

Now, in casting a glance over the long series of accurate experiments made by different distinguished individuals on specimens of air brought from districts the most remote, and collected under circumstances the most dissimilar, the point that most fixes the attention is the almost absolute identity of composition found every where to prevail. Air from

the summits of Mont Blanc and Chimborazo, from Egypt and from London, from Paris at the level of the Seine, and from a height of near 22,000 feet, exhibited the same proportions of oxygen and nitrogen. The carbonic acid and vapour of water are alone found to differ slightly. To what cause, then, can we attribute this extraordinary uniformity of mixture throughout the whole extent of the atmosphere, if its constituents are, as we know them to be, merely *mixed?* Oxygen and nitrogen differ in specific gravity. How comes it to pass they do not separate like oil and water, and arrange themselves in the order of their densities—the oxygen below and the nitrogen above? The answer to this question involves what is called the "principle of gaseous diffusion."

When two gases which have no chemical action on each other—as, for example, carbonic acid and hydrogen—are so arranged that the vessels in which they are contained communicate by a tube of narrow dimensions, it is observed, after a certain time, dependent upon the length and small diameter of the tube, that perfect mixture has occurred, and that hydrogen and carbonic acid are to be found in the same proportions in both vessels. This facility possessed by the two gases, of diffusion into each other, is not interfered with even when it is made to take place against the action of gravity by placing the two connected vessels in an upright position—the carbonic acid below, and the hydrogen above. Carbonic acid is, bulk for bulk, more than twenty times heavier than hydrogen; and yet, after a few hours

at the utmost, the two gases are found uniformly mixed.

There are many curious facts, known to the experimental chemist, which illustrate this principle, and which he accidentally meets with in the course of his labours. A bladder or thin caouchouc bag filled with hydrogen, and left for some time, is found to contain nothing but atmospheric air. Diffusion has taken place through its substance in both directions. A jar of gas standing over mercury becomes gradually deteriorated from admixture of air creeping in between the mercury and the glass, in consequence of the want of complete adhesion, or "wetting," between the metal and the solid; and the chemist is often put to no small trouble and inconvenience in order to guard, in his researches, against the effects of this ever-active principle.

A very curious and interesting law, linking together the rapidity of diffusion of the several gases and their density, has been discovered by Professor Graham, and its study will be found highly interesting to all engaged in the pursuit of natural science; it will be unnecessary to discuss it in the present instance, as the mere knowledge of the general facts above described will suffice to enable the reader to form some idea of the unspeakably important part played by this property or quality, inherent in the constitution of all gaseous substances, in the great economy of nature. There are processes constantly going on around us in which gaseous matter and vapours, prejudicial in the highest degree to animal life, are unceasingly evolved; the function of respi-

ration, the burning of wood and coal for fuel, are attended with the conversion of the free oxygen of the air into carbonic acid. By the putrefactive decomposition of animal and vegetable substances, poisonous principles, far worse than carbonic acid, are given off into the air. The volcanic vents, so numerous in both eastern and western hemispheres, discharge, as is well known, almost inconceivable quantities of noxious gas, chiefly carbonic acid, even when all traces of heat have disappeared, and no active eruption of lava has occurred within the historical period, as in the case of the ancient volcanoes of the Rhine.

The chief characteristic of the present phase of society, the crowding together of multitudes of men into towns and cities, and their employment in manufactures of various kinds, in very many of which gases and exhalations of the worst description are copiously evolved; and even without this, the mere aggregation of such a mass of human beings, each one unconsciously consuming the air of heaven and replacing it by poison, would speedily put a stop to life altogether. If the heavy carbonic acid, so copiously generated from these many sources, were simply to obey the natural law of gravitation, and spread itself out upon the surface in such localities, a state of things would arise only now to be paralleled by the condition of the hold of a slaver.

This, however, is not all. It has been stated that the atmosphere contains, as a mean, about one part in two thousand by volume of carbonic acid. It may also be shown, without much difficulty, that if

the whole carbonic acid of the air were collected into a stratum or bed occupying the lower part of the atmosphere, such stratum would have a thickness of about thirteen feet. Now let any one who wishes to gain a notion of the effect of such a layer of heavy, irrespirable gas spread over the whole ocean and lower part of the earth, gain admission to one of the large London breweries, and observe a sort of miniature representation of this state of things in the great fermenting vessels, filled to their upper edge with this gas, disengaged during the conversion of sugar into spirit. Let him consider what would be the condition of men, if each continent and island were separated by an invisible ocean of poisonous gas, as impassable as the barrier between the dead and the living, encroaching even upon the land itself, filling the valleys and lower levels, and causing instantaneous death to the unfortunate being who should for a moment be plunged beneath its treacherous surface.

It may, however, be said, and with great truth, that such a state of things is impossible. Carbonic acid is freely soluble in water; no reason can be assigned why this power of solution should not be exercised by the water of the sea upon the gaseous stratum above described, the effect of which would of course be its total disappearance, the gas being held in complete solution in the ocean water. Man would then have no reason to dread asphyxia by carbonic acid; if any creatures suffered, it would be the inhabitants of the water, to whom, in all probability, this great additional quantity of carbonic acid

and of carbonate of lime, speedily taken up, would prove highly noxious; but there is another most important consideration, which must not for a moment be allowed to remain out of sight.

The dependence of animals for their food upon the vegetable world, is easily seen: where no vegetation exists, there can be no animal life. Now, as will hereafter be shown, plants in their turn depend in very great measure upon the atmosphere for their sustenance; they get their carbon from the air, by decomposing the carbonic acid it contains. Carbonic acid, in small quantities—for an excess is destruction—is absolutely indispensable to the existence of vegetable life, and if it were withdrawn from the atmosphere in the way supposed, the latter must cease from the face of the globe, and with it vitality altogether.

Thus it is that, in all the arrangements of the material world whose details science has brought to light, the bodies and agents employed have been so chosen with reference to *all* their properties and mutual relations, that the slightest imaginable change in the latter may often be strictly shown to be incompatible with the safety and equilibrium of the whole.

The oxygen and nitrogen, too, instead of being uniformly mixed throughout the whole atmosphere, as at present, having the energetic chemical powers of the one modified and softened—diluted, as it were—by the other, would form two immense layers of unequal thickness, arranged in the order of their densities, the oxygen below and the nitrogen above.

In such an order of things as this, animal existence would be out of the question: an atmosphere of pure oxygen is as fatal to life as one destitute of that element—all the phenomena of combustion and oxidation generally would be exalted tenfold in power and energy; in fact, the present arrangement of nature could not be maintained in its integrity a single hour.

The equable diffusion of vapour of water through the atmosphere, is no less important than that of the carbonic acid. In many warm countries, during a great part of the year, rain seldom or never falls, and it is only from the copious dews deposited in the night that vegetables derive the supply of moisture required for their growth, and to sustain them, by the cooling effects of evaporation, from the scorching rays of the noon-day sun. Were the invisible elastic steam disengaged from the surface of the sea, or other large bodies of water not subject to the diffusive law in question, it is probable that other and very different phenomena would be observed.

To take another case, not perhaps so striking to the casual observer, but equally important in the eyes of the attentive student. In respiration, the object of which is to bring the blood in contact with the oxygen of the air for the purpose of effecting changes hereafter to be described, the lungs are alternately filled and emptied by the mechanism of the respiratory muscles, internal and external, and the air from without thus finds its way into the minute cells which terminate the last ramifications of the bronchial tubes; here its oxygen is made to

act upon the venous blood, while the latter disengages carbonic acid in place of the oxygen absorbed. Now in expiration, even when forced, the lungs are very far from being completely emptied of air, and that which is thrown out is in a great measure derived from the larger tubes and passages, the ultimate cells in which all the real business is performed, remain filled with the vitiated air which must be displaced, if the function is to be continued, by other means more efficacious than the gentle pressure of the elastic thorax. Here it is that diffusion comes into play between the oxygen of the *tubes* and the carbonic acid of the *cells;* the latter is speedily removed and replaced by the former, and expelled from the body by the next following expiration.

Such, then, are some of the leading consequences which follow from this one single property of gaseous bodies, their diffusibility into each other; we have seen how essential this property is to the present order of nature, and indeed to our very existence; it is not less pleasing to follow its consequences in this more humble office of administering to our happiness and pleasures.

Who does not inhale with rapture the perfumes of a flower garden when the dews of night, or the refreshing summer shower, have awakened the thousand sweet odours of its fair inhabitants! The breath of the hawthorn and of the rose have been always one of the most favourite themes of the poet's song; they have ever been associated with the purest and sweetest imaginings of tenderness

and affection; and yet this endless succession of pure and simple pleasures is but a mere consequence of the law which bids a vapour, arising by its own elasticity from a volatile substance, mingle itself with the surrounding air, and extend its influence until its effects become so enfeebled by dilution as to be imperceptible to the sense.

ON THE

CHEMISTRY OF ORGANIZATION.

From the consideration of the earth and its gaseous envelope, we now turn to the still more interesting subject of the chemical history of its organized denizens. The phenomena of life, both in animals and plants, are the result of a power or force not existing elsewhere, under whose control, growth, or increase of volume and weight, takes place, by the introduction of new matter from without, in a very extraordinary manner—by the development, namely, of multitudes of little cells or membranous bladders containing a fluid. These cells become afterwards modified in various ways, but their appearance is always antecedent to the production of circulating vessels, or, indeed, of any of the more complex forms of organic structure.

The membrane which constitutes the cell-wall is freely permeable by fluids, and consequently, by gaseous matter soluble in those fluids; food is thus carried into the interior of the mass for the nourishment of fresh generations of cellules, each produced from a living point or germ within the substance of a pre-existing cell.

This is all that the microscope makes known to us, and it must be confessed that it is little enough.

The most wonderful property of the living cell is its power of influencing chemical action; what is called "secretion" in animals and plants is the result of the exercise of this function; growth itself is a consequence of it, for the cell secretes or prepares its own food. And what is still more astonishing, different *kinds* of cells possess different powers in this respect; one shall decompose carbonic acid, reject the oxygen, and unite the carbon, so eliminated, to the elements of water; a second shall produce, out of the inorganic constituents of the air, the odoriferous principle of the rose; a third shall convert the albumen of the blood into the azotized principle of milk; and yet to the eye all are alike—all little wet bladders!

It is in the vegetable world that the formative power of this extraordinary agent is most evident in the generation, out of purely inorganic matter, of all the substances visible in the plant itself. Every green leaf, every part which can perform the duty of a leaf, is the theatre of these wonderful events—these strange decompositions which we cannot imitate.

In an animal, however, the case seems different; the vital force is, in some measure, occupied in shielding from decay the fabric of the body. The chemistry of life is not here of so lofty and subtle an order as in the plant; it is confined to the modification, the change of complex organic principles already existing—principles which, as we shall see,

owe their origin to plants. A building up, an organizing power, is indeed manifest; but the materials are furnished, as it were, to its hand, in a state requiring, at the utmost, an exertion of chemical force infinitely less energetic than that required to produce woody fibre, or sugar, from carbonic acid and water.

It will be convenient, therefore, for the present, at least, to admit the existence in plants and animals of a peculiar power, which we may call "vital force," distinct from ordinary chemical attraction, but having relations with the latter, as close and intimate as those which connect chemical and electrical phenomena.

There is, perhaps, at the present moment, no department of natural science which offers so rich a reward to patient and diligent investigation, as the chemical study of the almost endless series of proximate organic principles formed by the union in various ways among themselves, of the four elementary bodies, carbon, hydrogen, oxygen, and nitrogen. It cannot fail to excite the attention of the most superficial observer, to discover that substances possessing properties of the most opposite kind should be made up of the very same materials—that the sweet crystallizable principle of the sugar-cane, the bitter febrifuge of the willow-bark, the fixed and permanent acid of the grape, the highly volatile acid of vinegar, and many other equally well-contrasted substances should be composed of the same three elementary bodies, carbon, hydrogen, and oxygen, merely differing slightly in the proportions in which

they are associated. A very few grains of the vegetable alkali morphia, or a fraction of a grain of another member of the same chemical family, strychnia, will destroy life; the bread we subsist upon owes its nutritious power to a combination of the very same elements which, in other circumstances, give origin to the poisonous juice of the poppy, or the still more deadly principle of the nux vomica. The slightest difference in the relative proportions of the constituents of such compounds may give rise to the utmost conceivable discrepancies in their chemical relations.

This, however, is not all; it has long and justly been held a kind of axiom in chemistry, that the "same chemical compound must always contain the same elements, united in the same proportions." The converse, however, to this proposition is not true; two or more bodies uniting, in constant proportions, do not of necessity generate the same substance. We may have, not merely two, but a whole series of compounds, differing as much from each other in all respects, chemical and physical, as the imagination can conceive, and yet one and all be made up of the *same elements, joined together in the same proportions.*

This most curious and unexpected discovery was, at first, and very properly, received with doubt and distrust, as a false result, due to inaccurate research, and it was thought that, as practical analysis became more strict, differences of composition would be found in these cases, fully adequate to account for the discrepancies of characters observed. This anticipation, however, has not been verified: within the last few years organic chemistry has made vast

advances in every department of the science; the analytical methods of research have been greatly simplified, and increased in delicacy; but instead of a refutation of the new doctrine, by appeal to more exact experiments, it has been strengthened and extended by almost every labourer in this fertile field. The number of "isomeric bodies," as these are called, where identity of composition is associated with diversity of qualities, is at the present moment very great, and every year increases their number; they are to be found in nearly every section of the science, and constitute its most striking and characteristic feature.

Here, again, is another illustration of the truth of the remarks already made respecting the very peculiar nature of the four ultimate organic elements. It is not denied that cases occur in mineral chemistry which seem to be the analogs of the isomeric substances of the organic world,* but these are few and far between, and would, perhaps, have escaped notice altogether had not attention been strongly excited by the discoveries just mentioned.

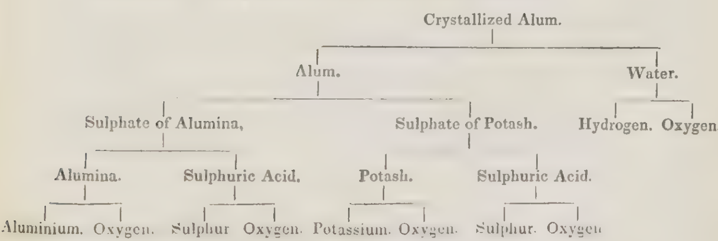
An attentive study of the chemical history of the proximate organic principles will soon raise in the observer a conviction of the great and essential difference in constitution and structure, so to speak, between these bodies and the salts and oxides, and other compounds of inorganic chemistry. As some importance is attached to such distinction, it may not be improper to discuss it in sufficient detail to ren-

* Phosphoric acid; *perhaps* chromic acid, and one or two other bodies.

der it intelligible to the reader whose knowledge of elementary chemistry is but slight.

In all the combinations of the metals and non-metallic substances, the investigation of which constitutes mineral or inorganic chemistry, a principle, or mode of union, is every where found to prevail, which we may term the "binary" mode of combination. This is sufficiently easy to understand, if we consider one or two cases, which may be taken as types or representatives of the rest. The very familiar salt, alum, we have every reason, at the present moment, to consider as a direct compound of two other saline substances—namely, sulphate of alumina and sulphate of potash. Each of these in its turn is generated by the union of a pair of bodies —sulphuric acid and alumina on the one hand, and sulphuric acid and potash on the other. These are, however, themselves compounds. The acid is an oxide of sulphur, the bases are the oxides of the two metals aluminium and potassium.

Perhaps the following diagram will give an idea of the successive steps of pairing in the formation of a complex inorganic substance like alum,—first, between acknowledged elementary bodies; then, between compounds of the first order; and, lastly, between two complete oxygen-acid salts:—



There is a curious salt now used in the arts for tinning and soldering copper, or rather for assisting in these processes. It is made by mixing together solutions of sal-ammoniac and of chloride of zinc in certain proportions, and evaporating down the liquid until the new body separates in crystals on cooling. This substance consists of chlorine combined with zinc, and with the radical or basis of the salts of ammonia. We do not, however, for a single instant, imagine that, in this, or any analogous case in inorganic chemistry where three bodies are concerned, union among them occurs in any other way than in that described—namely, in dividing one between the other two, thus generating a pair of binary compounds, which, by uniting in their turn, give origin to the body itself. In the example cited, the salt in question, the "chloride of zinc and ammonium," is looked upon as a true double salt formed by the union of a pair of chlorides; and this view of the matter is supported by direct experimental evidence of unquestionable weight and authority.

Such, then, is the great characteristic feature of all inorganic combinations—progressive union of pairs of substances, simple and compound. The case of the proximate organic principles, to the consideration of which we must now return, is strikingly different.

In the majority of these substances we find the three or four elements so often mentioned—carbon, hydrogen, oxygen, and nitrogen—associated in a way quite new and peculiar,—a fashion of union altogether different from the binary or inorganic type; in

accordance with a plan, in short, which is unknown in the other division of the science. Instead of combination by pairs, we see three or four substances bound up together in a single group, constituting one indivisible whole, susceptible of entering into combination, and being thence disengaged and set free without change or alteration. For example, one of the most familiar substances of daily life, sugar, is a true chemical compound of carbon, hydrogen, and oxygen, in which the two last named elements exist in such proportions, that if they were united they would form water. Hence sugar is said to consist of carbon and the elements of water; and some have even gone the length of supposing it really to contain water itself, ready formed, to be in short a "hydrate of carbon;" but this idea is unsupported by the evidence, which leads to a conclusion altogether different—namely, that the sugar is, as already stated, a direct combination of the three elementary bodies.

We thus get acquainted with quite a new class of substances—a set of *ternary* and *quaternary* compounds, which may be expected to possess characters and properties quite peculiar; and this is really found to be the case. It is well worthy of observation also, that the organic type spoken of is very often obstinately retained even after the vegetable or animal principle has been subjected to very important modifications by powerful chemical re-agents. The stamp of vital origin often resists for a long time the means taken to destroy it, and the result is very frequently the production of an extended series

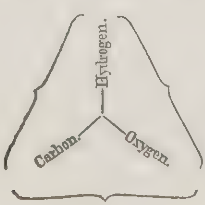
of curious products in a kind of descending scale, gradually decreasing in complexity of composition.

When sugar is placed in particular circumstances, hereafter to be noticed, it undergoes conversion into alcohol or spirit of wine, carbonic acid being at the same time produced. This alcohol is a true ternary substance like sugar itself, but *simpler in constitution.* Again, alcohol is freely convertible into acetic acid by the loss of some of its hydrogen, and the acquisition of oxygen in its place. Acetic acid, in its turn, can be decomposed by appropriate methods, and made to furnish a third ternary substance still less complex—namely, pyroacetic spirit or acetone. This is an example of a succession of three descending steps, through which a complex organic compound may be made to pass without losing the peculiar and characteristic features of its origin; and it would be very easy to adduce many more. The animal principle, uric or lithic acid, one of the most interesting bodies in existence, may be made to furnish a most remarkable and very numerous family of new substances, each of which is a true organic principle, although not always directly found in either the vegetable or animal kingdom. Indeed, by far the greater number of objects included within the domain of organic chemistry are bodies formed in this half-artificial manner from the educts, as they are sometimes called, of organization, the direct results of the chemistry of life.

A very important consequence of the ternary or quarternary structure of organic bodies in general

above described, is the weakness and instability which result from such an arrangement. It is easy to see, in some measure, the reason of this. If an inorganic substance, even of highly complex nature, be attentively considered, it will be observed that the arrangement of elements is usually such as to give rise to a condition of stable equilibrium, to satisfy, as it were, in the fullest possible manner, all the chemical appetites or tendencies of the elements concerned. In the case of the alum, for example, the two metals, the hydrogen and the sulphur, are already united to as much oxygen as they have, *under the circumstances*, any atttraction for. The same is true of the compounds so generated, each base being associated with just so much acid as it requires to form a definite compound; no cause of decomposition exists capable of bringing about a change, short of external agency sufficiently potent for the purpose.

Contrast this with an organic principle—sugar, or acetic acid—to take a simple case; and as we have ventured to represent the constitution of an inorganic compound, let us do the same now with one of the second kind: let us represent our ternary substance after the following manner, by way of distinction—



and consider what must of necessity take place. The oxygen and hydrogen tend in the strongest manner to unite, and form water; they are prevented from doing so by the attraction of the carbon for both of them individually, while for their compound, water, that element *has no apparent affinity whatever*. The same is true of the other possible direct combinations; carbon and hydrogen, carbon and oxygen, possess mutual attractive powers, but union between them is impossible so long as the opposing force of the third element exists in sufficient intensity.

The state of equilibrium of forces in such a body must be very different from that in one of the inorganic substances formerly referred to; it must be far weaker, and more subject to derangement. The elements are held together by a kind of balance of opposite attractions, and remain united only while that balance is exactly maintained. A small external disturbing force—a slight alteration in the intensities of the attractive forces themselves, and the combination is broken up—the liberated elements arranging themselves in another and more stable order, giving rise to one or more new bodies.

In fact, the organic principles for the most part seem to owe what permanence they possess more to some *vis inertiæ* than to any inherent strength of their own. They have been produced, in the first instance, under the immediate influence of vegetable life, in circumstances which we cannot imitate, and, in fact, do not understand; and they only maintain their integrity afterwards in the absence of disturb-

ing causes. They contain within themselves the principle of their own dissolution, ready to be called into activity by the slightest apparent cause.

It must not be imagined that the bodies in question are all equally weak and instable in constitution; the differences among them in this respect are very striking and well marked, and serve to bear out and confirm in the strongest manner the truth of the principle attempted to be laid down. We find, as a general rule, that those compounds are *most* prone to rapid and facile decomposition which contain the *greatest* number of elements, and the most complex arrangement of these elements; while, on the other hand, there are organic bodies so permanent in their nature, and so little subject to change, from simplicity of constitution, as to approximate in their characters to mineral substances, and often form, in fact, a kind of connexion between the two great sections of chemical science. As examples of such, may be noticed oxalic acid, cyanogen, ferro and sulpho-cyanogen, and many of their derivatives; certain hydrocarbons, &c.

There is a physical character which will sometimes aid us in giving a good guess as to the simple or complex constitution of an organic substance—the faculty of crystallization. It is not meant to be affirmed that this character is, in all cases, implicitly to be relied on, but simply that it is highly useful in practice, and has certainly some intimate connexion with the molecular structure of bodies.

This power of assuming on solidification a distinct and often very characteristic geometrical form,

appears to be possessed by all chemical compounds of definite and constant composition, with the exception of a certain number, principally to be found in the class of organic substances of the most complicated and instable chemical nature. We know nothing, and apparently at present can know nothing, of the ultimate structure of any substance whatever, but it is not difficult to figure to one's self some idea of the gradual weakening of the molecular forces, upon which crystallization depends, whatever the nature of those forces may be, by an increase in their number and in the multiplicity of directions in which the forces themselves are exerted.

It very often happens that, in these cases where crystalline texture is altogether absent, we observe in its place an appearance of a very different kind; we notice that the smallest particles of matter which can be traced by the microscope exhibit a rounded or globular figure instead of the straight lines and angles of the crystallizable compounds. These very frequently appear to aggregate together in strings or rows, not altogether unlike some of the very lowest structures of the vegetable world, where a commencement of organization is, as it were, just visible. The substances forming the chief constituents of the animal body are in this condition; these are, it is certain, the most highly complex of all chemical compounds known, and the most subject to rapid and destructive change, as we shall hereafter have an opportunity to see.

It would be easy to extend these observations much further, but it is hoped that enough has been

said to establish the proposition that "the selection out of the whole number of elementary substances of the four organic elements—carbon, hydrogen, oxygen, and nitrogen—for the purposes of organization, was expressly made from a full previous knowledge of the very extraordinary chemical properties possessed by these substances by which they alone are fitted for the objects intended." Design, therefore, is proved.

VEGETABLE CHEMISTRY.

The proximate organic principles already known and examined, directly derived from plants, are very numerous, and every year adds to the list and to our knowledge respecting them. The majority of these, however, are bodies which occur in very minute quantity in certain particular vegetables; and although highly interesting to the scientific chemist on account of their curious properties, and important to mankind in general from the powerful medicinal virtues they often possess, form too small a portion of the body of the vegetable in which they occur to require a lengthened description in a treatise where the object is more to give an idea of the general functions in Nature of the chemical elements on the great scale, than to impart specific information concerning individual substances and their relations, which may be learned by consulting any one of the several excellent elementary works on chemical science which now exist, both in our own language and in those of the Continent.

There are, however, some few of these bodies so

universally diffused through the whole vegetable world, and so important and valuable in every respect, that it is indispensable to make some acquaintance with them before entering upon the somewhat difficult subject of the food of plants.

We shall take them in the order found most convenient in this study.

The proximate vegetable principles may be divided into two classes — namely, those containing nitrogen, and those destitute of that element. It will be convenient to consider the latter division first.

The principal groups of substances contained in this section are the following: — 1. Saccharine and amylaceous bodies. 2. Vegetable acids. 3. Fatty and resinous principles.

THE SWEET PRINCIPLES OF PLANTS seem to be rather numerous; already five or six distinct bodies of this kind have been pointed out and examined, and it is probable that others exist which are yet undescribed. Thus, one particular kind of sugar abounds in the juice of the sugar-cane, in beet-root, and parsnips; a second constitutes the sweet matter of all ordinary fruits; a third is found in certain fungi; a fourth in the common liquorice; a fifth exists in manna, which is an exudation from a species of ash, *fraxinus ornus*, common in southern Europe; the eucalyptus-sugar of Van Dieman's land, recently described by Professor Johnston, probably belongs to the last-named modification.*

* Memoirs of Chemical Society of London, vol. i. p. 159.

All these substances closely resemble each other in many points, while at the same time sufficient difference of character exists among them to establish their separate identity. Manna-sugar exhibits the least agreement with the rest of the group in its composition and properties.

The two modifications of the sweet principle first mentioned — namely, the sugar of the cane and the sugar of fruits, or, as it is commonly called from its most abundant natural source, the sugar of grapes, alone possess sufficient interest and importance to require description.

The first of these, an article of luxury rendered by habit almost a necessary of life to every class of the community, is prepared in enormous quantities from the juice of the sugar-cane in most of the warmer regions of the earth where the climate admits of an advantageous cultivation of that plant. The tropical colonies of Great Britain alone furnish an immense supply of this now indispensable article. In France, and elsewhere on the continent of Europe, sugar, identical with that of the cane, is manufactured from beet-root on a scale of considerable magnitude, but the process is, in this case, much more troublesome from the greater proportion of impurities in the juice of the latter.

The meadow grasses of our own country contain a sweet substance, occasionally in some abundance, which may very possibly be ordinary cane-sugar, and it is to this that much of the value of these plants as food for cattle may fairly be attributed.

Although the theory of the sugar manufacture is

simple enough, the practice is beset with difficulties and attended with loss and injury of material arising from the extreme susceptibility of change of the cane-juice itself. The latter, as it runs from the crushing-mill, is as clear and nearly as colourless as water; but a very short exposure to the atmosphere, in those warm regions, suffices to set up a commencement of decomposition which rapidly advances, and in a short time converts the sweet-tasted bland liquid into a spirituous or ascescent product, turbid from insoluble suspended matter, and totally unfit for the purpose to which it was intended to be applied. To guard against this evil, the sugar-boiler always endeavours to conduct the first part, at least, of his process as rapidly as possible; he heats the freshly expressed juice in a large vessel to near the boiling point, having previously added a little slaked lime to neutralize a small portion of free acid always present in the liquor, the effect of which in the after part of the operation is very pernicious. By this proceeding a solid flaky substance, the nature of which will shortly be mentioned, separates, and the clear liquid being removed by a syphon or otherwise, is rapidly evaporated down in open pans, until the syrup becomes strong enough to yield crystals of sugar after cooling.

The product of this operation is the crude or muscovado sugar of commerce; this is seen on close inspection to consist of small but distinct crystals of sugar, stained and rendered impure by dark-coloured uncrystallizable syrup or molasses, which latter substance does not pre-exist in the juice of the cane,

but is produced at the expense of some of the crystallizable sugar by the high temperature used in the concentration of the saccharine solution. Raw beet-root sugar is a far worse article than that from the cane, and is, indeed, almost unfit for use until refined.

The refining process is as simple as the original manufacture: the operator makes choice, if circumstances permit, of what he calls a *strong* sugar, that is large in the grain, very distinctly crystalline, not caring so much about the colour, which he has it in his power to remove; he dissolves this in water, mixes it with albumen, white of eggs, or serum of blood, and heats the whole to ebullition, by which the albumen is coagulated, and certain mechanical impurities removed with the coagulum from the liquid. The next point is to whiten or decolorize the syrup, which is done by filtering it through a bed of coarsely-powdered animal charcoal, which possesses the singular property of absorbing various organic colouring matters; it comes through very nearly colourless, and only requires to be concentrated by evaporation to yield pure sugar. In the best refineries this evaporation, instead of being conducted at a high heat in open vessels—whereby a second loss from the formation of uncrystallizable syrup, besides an increase of colour in the whole product, would infallibly ensue—is carried on in strong metallic boilers, or stills, of peculiar construction, exhausted of air by a powerful engine. By this diminution of pressure on the liquid, its boiling point is reduced to about 150° F., and all blackening prevented.

In the western parts of North America, an excellent sugar is extracted from one of the maples—the *acer saccharinum*, common in those parts. The tree is tapped, in the spring, by boring an auger-hole a little way into the wood, and the juice collected in a vessel below, and evaporated in a common iron pan to the requisite density for crystallization. This sugar, which is an article of great value to the inhabitants, is chiefly employed by them for domestic uses, very little being exported.

In white candy or the finest loaf-sugar, we have the substance in a state of very high chemical purity, the only difference between them being the same as that seen on contrasting calcareous spar with white marble; the one exhibits large and distinct crystals, the other a confused assemblage of small ones.

The most obvious properties of this very interesting substance, its free solubility in water, pure sweet taste, and other evident characters, are too familiar to every one to need notice here; its relations will be discussed in conjunction with those of the other members of the great series to which it belongs.

Sugar of Grapes, the ordinary sweet principle of ripe fruits.

This variety of sugar may be obtained in large quantity from the sources above mentioned, by a proceeding very similar to that by which ordinary sugar is extracted from the cane. We possess, moreover, the power of artificially producing this substance by a modification of the two next bodies to be described, starch and woody fibre.

Grape-sugar is easily to be distinguished from the other kinds; it crystallizes from its watery solution slowly and with some difficulty, while the crystals thus obtained are very confused and indistinct, and rarely exhibit brilliant faces. It is much less soluble than cane-sugar, and very inferior in sweetness, which latter circumstance interferes with its application to economical purposes. Grape-sugar is further distinguished by its behaviour with respect to heat, and various energetic chemical agents, acids and alkalis. It seems to be, upon the whole, a much more stable and permanent substance than the variety first discussed, and most probably has a simpler chemical constitution.

Starch, or Fecula, is a body of great interest in many respects, from its universal occurrence in the vegetable kingdom, the important objects it there fulfils, and, lastly, the curious changes it may be made to undergo in the hands of the chemist.

There is scarcely a plant, or part of a plant, which, when closely examined, does not yield more or less of this substance; not unfrequently the quantity is so great as to produce in the plant the appearance of deformity by enormous distention of the cellular tissue in which the starch is contained. We have examples of this in the common potato, a fleshy, under-ground stem, bearing buds upon its surface, but swollen out of all shape and figure by an accumulation of starch mingled with water within each individual cell: in the roots of certain orchideous plants, and in very many others where a soft and succulent character is observed; the plant which

furnishes arrow-root, a mere variety of starch, is a case of the kind; the interior of the stems of many palms is often filled with loose cellular substance, rich in starch; and, lastly, it constitutes a very important, and often very abundant, ingredient in seeds of all kinds.

The simplest and most expeditious method of obtaining this principle is perhaps the following:—potatoes after being pared are grated or rasped to a pulp; this pulp is put upon a sieve, and stirred about, while at the same time a little stream of water is made to flow upon it. A milky liquid runs through the sieve, and may be received in a basin beneath; this, after a few minutes' rest, deposits a white powder, which is the starch itself. By this simple mechanical process of tearing up the vegetable tissue, and removing the enclosed starch by washing, that substance may be got from a great variety of plants, although not always with equal facility.

Starch is insoluble in cold water, as the above mode of preparation necessarily implies. It presents to the naked eye the aspect of a white powder, having sometimes a brilliant silky lustre, which, under the microscope, is too remarkable in its appearance to fail in arousing the attention of the observer. By an instrument of good power, it is seen to consist of a multitude of little transparent rounded grains, quite destitute of crystalline structure, but present-

ing, on the contrary, traces of an organized arrangement, giving the idea of little eggs or seeds. A dark spot, or "hilum," is seen at one extremity, surrounded by a number of parallel rings or striæ, which cover the whole surface of the granule, and seem to be depressed or cut into it.

The magnitude of these starch granules is very different in various plants; in the potato they are often very large, about $\frac{1}{200}$ of an inch in diameter; in arrow-root considerably smaller, while in the fecula from the grain of the cereals, they are very small indeed. The size and appearance of the granule afford almost the only method of distinguishing one variety from another.

When starch is put into cold water and gently heated, a change takes place by which the properties of the substance are completely altered. At a temperature a little short of the boiling point of water, the granules break or burst, and their contents are acted upon, giving rise to a nearly transparent gelatinous mass, freely miscible with water, if not really dissolved in that liquid, and in which float about numerous minute shreds of membranous matter, easily discovered by the microscope. Now, there is some diversity of opinion respecting the real structure of starch, and the nature of the change it undergoes by the action of hot water; the most probable explanation seems to be that the grains

consist of a soluble matter enveloped in a fine membrane, which is rent, or otherwise destroyed, at a high temperature, and the internal substance attacked; so that each granule must be looked upon as an organized membranous cell, filled, like the fat-cells of the animal body, with a peculiar matter, itself altogether destitute of organization, and, in fact, a mere chemical compound; we may call it, for the sake of distinction, "amidine," or gelatinous starch. This view is strengthened by the following fact:—amidine is destitute of nitrogen; it contains nothing but carbon, hydrogen, and oxygen; now starch, analyzed *as a whole*, always gives a little nitrogen, which may reasonably be supposed to rise from the organized integument, such structures in plants, as well as in animals, often containing nitrogen as an essential component. It is unwise, however, to give a decided opinion on this subject; the phenomena observed by several recent experimenters, are very curious, and not easy to reconcile to this simple view.*

When thick gelatinous starch is boiled for a few minutes with dilute acid of almost any kind, a little weak sulphuric acid for example, it undergoes another remarkable alteration; from a viscid mass it changes to a fluid as limpid as water, and if the acid be now withdrawn by saturation, and the liquid gently evaporated to dryness, it furnishes a substance having many of the characters of gum, but differing in some respects from that substance.

* See papers of MM. Payen and Jaquelain, in the Annales de Chimie et de Physique.

To this new body the name "dextrine," or gummy starch, has been given; its *chemical composition is exactly the same as that of gelatinous starch.*

If, now, instead of interrupting the ebullition as soon as the mixture has become thin and clear, we continue it for the space of several hours, adding from time to time small quantities of water, to supply the place of that lost by evaporation, and then separate the acid by chemical means, and boil down the clear solution to a small bulk, we get a syrupy liquid, very sweet to the taste, which, on standing for a few days, entirely solidifies to a mass of grape-sugar, exceeding in weight the starch from which it was produced.

In these curious transformations, the acid employed undergoes neither change nor diminution. It is all withdrawn in its original amount after the experiment; nothing is absorbed from the air, and no other substances but dextrine or grape-sugar generated; and a reference to the chemical composition of the substance employed, and that obtained, easily shows that the whole affair lies, in fact, between the amidine and the elements of water, grape-sugar containing more oxygen and hydrogen, compared with the quantity of carbon, than starch.

Such is a brief notice of this extraordinary change, in which common potato-starch may, at pleasure, be made to yield more than its own weight of sugar of grapes. There are, however, other methods by which the same end may be effected. If a little common malt, barley made to germinate,

be roughly powdered and infused in tepid water, a solution is obtained which exhibits the same power as the dilute acid of converting a large quantity of thick starch first into dextrine, and finally into sugar. It is sufficient, in order to show this fact, to mingle some gelatinous starch with a small quantity of infusion of malt, and expose the whole to a gentle heat, not exceeding 160° F. In a very few minutes it becomes thin like water; and if the temperature be kept up during three or four hours, the liquid becomes sweet to the taste, and is then found, on examination, to be rich in grape sugar.

The conversion of the starch into sugar is supposed, in this case, to be due to the presence of a substance in the malt, or germinated grain, called "diastase," imagined to exist in all seeds under similar circumstances, in active buds, and probably elsewhere. Attempts made to isolate this curious body have not been very successful. So far as is known, it seems to belong to the class of vegetable albuminous principles—a class of substances second to none existing in importance to the economy of organization, as we shall have occasion to see. The quantity of diastase necessary to effect the above-described metamorphosis is very small. Its action, although most energetic at a moderately high temperature, is said to be still perceptible at a much lower one, even that of the air. A boiling heat annihilates its specific power by causing coagulation and insolubility.

These remarks will suffice to render to a certain degree intelligible the beautiful order of arrange-

ments by which plants are furnished with a sudden and copious supply of already assimilated food at certain particular periods of their life, when the drain upon the natural powers is excessive, or when the plant, from its feeble and undeveloped state, is unable to obtain and digest food from without. Every one is familiar with the fact, that a very large proportion of the vegetable inhabitants of the temperate zones, at the close of every summer, either perish completely, or die down to the roots, which remain in the ground until the following spring. It is not uncommon to attribute this effect to the increasing coldness of the season—to the nipping frosts of the fine clear autumn nights. A far more efficient cause is, however, to be found in the plant itself, whose death is the result of the exhausting nature of the process by which provision is made for another generation of similar beings. The periods of inflorescence and seed-bearing are attended with a large expenditure of costly material. The development of a flower is a very different affair to that of a green leaf. The former contributes nothing to the general maintenance of the plant; while the latter is at once a new mouth, and stomach, and lung, capable of contributing its share to the general good. In the formation of the fruit and seeds, also, soluble gummy and saccharine matters are conveyed to these points and there fixed, to the manifest detriment of the whole system, which suffers by the withdrawal of these substances. Now, it is to guard against, or at any rate to diminish, these evil consequences of a necessary function, that Nature usually

employs the time previous to flowering, when the vegetative power is most active, in storing up, in different parts of the plant, a quantity of starch, ready for use when the pressing occasion arrives, at which time it is re-dissolved, by the aid of diastase or some similar substance perhaps, and once more added to the general stock of nutriment. There is reason to think, that were it not for this contrivance the maturation of seeds could hardly take place. As it is, the latter process is no sooner completed than the plant exhibits every sign of exhaustion, and in very many cases dies altogether. The starch, thus transferred from the parent plant to the seed, remains unaltered sometimes for years, until external causes arouse into activity the vital energies of the germ. The development of the latter commences while the starch, slowly passing into a soluble state, furnishes, in conjunction with the albuminous portion, a constant and ready supply of food, until the radicle and leaves are sufficiently advanced to exercise vigorously their specific functions.

The conversion of starch into gummy matter and sugar, and that of the latter again into starch, seem to be very common in the vegetable kingdom. It has been shown, for instance, that in the ripening of fruits, such as apples and pears, starch first deposited disappears, and sugar is found in its place. Many of these phenomena are at present very imperfectly understood. Enough has, however, already come to light to exhibit to the patient and attentive observer glimpses, as it were, of a general design of

the most surpassing beauty of contrivance; and we have good hope that the unprecedented progress which chemistry and the allied sciences are now making, will, ere long, render much clear and intelligible which is now dark and perplexed.

Woody Fibre—Lignin.—By this expression is meant that very essential portion of every plant which remains behind, after the action on the vegetable tissue of various solvents, such as water, dilute acid and alkali, alcohol and ether, successively applied, by which sugar, gum, resin, colouring matter, &c., are each in turn removed, and nothing is left but a kind of white fibrous skeleton, insoluble in all those media. Fine linen or cambric will give a very good idea of the lignin of the chemist.

When examined by a good microscope, the ultimate fibres of lignin present the appearance of minute flat ribands, with rolled or thickened edges. These are no doubt distinctly organized, and very complex in chemical constitution.

Lignin may be converted into sugar by artificial means, passing like starch through an intermediate state, resembling dextrine.

Gum.—This is another very abundant vegetable product. Gum-arabic, from an acacia, and the gum of the cherry and plum-tree, are familiar to every one. Gum often exudes from wounds in the bark; and it is doubtful whether it is not, in some measure, a product of disease. This substance is one of great importance in many of the useful arts, being employed in large quantities; it never crystallizes, and is

easily distinguished, by its peculiar chemical characters, from the other vegetable principles. Many varieties, obtained from different trees, exist.

Such are the principal members of the very important class of neutral, non-azotized, vegetable principles. Several other substances, of less interest, belong to the same division, and have been passed over without notice; it remains to describe the chemical nature of these bodies. They are, as already stated, ternary compounds of carbon, hydrogen, and oxygen; with this very remarkable feature, that the two latter elements are present invariably, with perhaps one exception—*in the proportions to form water.* This ratio of the oxygen and hydrogen may be taken as one great distinctive character of the group; it is found elsewhere, it is true, but only in a very few bodies—such as lactic and acetic acids—derived immediately or remotely from some one or other of the series. Another good character is that of neutrality—disinclination to form chemical compounds with other substances; they do, however, occasionally combine in a definite manner, but with a degree of energy very far feebler than that observed in the case of many other organic principles. Thus sugar and starch unite with lime and oxide of lead: starch with iodine, forming a well-known blue compound of great beauty of tint; and many other cases might be mentioned, so that the term "neutral" must be understood comparatively.

The VEGETABLE ACIDS claim a moment's attention. These occur, often in large quantities, throughout the whole vegetable kingdom; they are generated

in the plant for purposes yet, for the most part, unknown, and afterwards often become highly valuable to mankind in their applications to medicine and the useful arts. It is not unlikely, also, that a beneficial effect may be produced by these bodies upon the animals to which the plants serve for food.

The vegetable acids seldom occur in a free state, the most usual condition is in that of a salt of an alkali, or earth, or sometimes an organic alkaline principle; a salt of potash, with excess of acid, is very common. When a vegetable substance is burned, these organic acids are destroyed, and the bases, for the most part, converted into carbonates; hence the alkalinity of ordinary wood-ashes from carbonate of potash—a substance, in practice, entirely derived from this source, although, as before shown, this alkali is an original and essential constituent of the unorganized earth; it is collected by plants from the soil, and accumulated in their substance in an easily available form for the use of man. If it were necessary, in order to procure potash, to extract it from the earth itself, the trouble and cost of the process would be so great as almost to prohibit its use.

With respect to chemical composition, the vegetable acids usually exhibit a larger comparative quantity of oxygen than the other proximate principles; the most common of them—the tartaric, citric, and malic—are examples. They are destitute of azote.

Fatty substances—fixed and volatile oils.—The oils and fats form an important series of bodies, characterized, in a chemical point of view, by a de-

ficiency of oxygen, sometimes amounting to a total absence of that element; their highly combustible nature is connected with this peculiarity. Fatty matters, in some shape, although never entirely absent from vegetables, are only in some particular instances to be noticed in large quantity. Seeds are very often loaded with oil, or soft fat, which may be extracted from them by simple pressure, or by heating with water. All the vegetable oils of commerce are got in this way, with the exception of olive oil, which comes from the fruit.

The fixed vegetable oleaginous principles bear the strictest resemblance, in every respect, to the animal fats. They have, when pure, very little taste or smell; they cannot be converted into vapour without decomposition, and undergo, like the corresponding animal principles, a change, when heated with caustic alkalies, in which the fat is resolved into two new bodies,—namely, a fatty substance, having decided acid properties, and a kind of uncrystallizable sugar, called glycerine. These reactions have been made the subject of much admirable research, but the question is too purely chemical for the present essay; it is practically important, however, because it is by such a change that we get the very valuable article, soap.

The volatile oils are in general remarkable for their powerful odours—often very agreeable, sometimes otherwise. They are further distinguished by the facility with which they evaporate; a drop upon paper soon passes off, and leaves no stain. The odours of flowers and of certain woods are due to these

principles. The study of the volatile oils forms a very interesting branch of organic chemistry; and it is satisfactory to find that something has already been done towards elucidating the origin of these in the plant, and showing their connexion with the other proximate principles.* Volatile oils are often of great economical use: the oil of turpentine, for instance, in the manufacture of varnish, and other applications.

Closely connected with the above are the RESINS, of which we have numerous varieties. These are looked upon as oxidized volatile oils; and, in fact, it has long been known that the last-named substances, by long exposure to air, absorb oxygen, and assume the aspect of resin. The resins are insoluble in water, fusible, burn readily, and cannot be volatilized; they often possess acid properties, and form salts with metallic oxides.

We have now to consider the vegetable principles containing nitrogen; and these we subdivide into two sections — 1st, the VEGETO-ALKALIS; and, 2nd, the ALBUMINOUS PRINCIPLES.

In a systematic work on chemistry, it would be indispensable to devote a considerable space to the vegetoalkalis; they occur here and there in a few plants, always in very small quantities, but then their peculiarities of constitution, and extraordinary

* Allusion is more particularly meant to the researches of Piria and Dr. Ettling on salicin and the products of its oxydation; those of Cahours and Dumas, on potato-oil and valerianic acid, &c.

powers over the animal system, claim for them, with justice, a prominent place. These bodies are dangerous weapons intrusted to our care; they may be used for good or for evil; as a fearful poison or as a valuable medicament, according to the hands they fall into. And it is, to all appearance, not without special design, that nature has been so sparing in the production of such substances, and has so enveloped with difficulties their isolation, that the knowledge and possession of them are of necessity confided to few, and to those least likely to make a bad use of them. With respect to these, a very few words will suffice. The vegeto-alkalis are, for the most part, colourless, crystallizable substances, nearly insoluble in water, but dissolving in spirit, having an alkaline reaction to test-paper, and forming distinct and definite salts with the ordinary acids. They contain a tolerably large proportion of nitrogen, and are very little subject to spontaneous change.

Far more interesting bodies are the albuminous principles; it is only very lately that the full importance of these, in connexion with animal existence, has been made manifest. The recent invaluable investigations of Professor Liebig have put these substances in a very different position from that they formerly occupied in the estimation of chemists and physiologists. To discuss these matters fully, however, at present, would involve a too extensive anticipation of the subject of animal chemistry; let it suffice, therefore, to remark respecting one or two of the lower and more subordinate offices, if the term

may be permitted, which these substances fill in the general economy of nature.

The change by which sugar becomes converted into spirit is brought about, in all cases, by the agency of one or other of these principles. It has been shown that the conditions under which vinous fermentation takes place always involve the necessity of the presence of azotized organic matter of this peculiar kind, in the absence of which the most favourable circumstances of temperature, access of air, and degree of dilution, fail to excite in a saccharine liquid the alteration spoken of.

When a sweet vegetable juice, like that of the grape or the sugar-cane, is exposed to the air, at a temperature of 60° or 70° F., it is observed, after a few hours, to become turbid and muddy, while, at the same time, minute bubbles of gas are seen to arise from all parts of the liquid, and ascend to the surface, entangling, in their upward progress, a quantity of the insoluble matter just alluded to, and giving rise to a scum or froth. This simultaneous disengagement of gaseous matter, and production of insoluble, dirty white, flocky precipitate, from the clear vegetable juice, go on rapidly increasing for a certain length of time, depending very much upon the warmth of the surrounding air. After a while the action slackens, and eventually ceases; the greater part of the insoluble matter collects at the bottom of the vessel, a little remains at the top, while the great mass of the liquor once more becomes clear. If a portion be now drawn off from the sediment and ex-

amined, it will be found to have lost, in a great measure, its sweet taste, and to have acquired another quite distinct; it has also become intoxicating, and capable of furnishing, by distillation or otherwise, a colourless, inflammable liquid, easily recognized as alcohol. The gas evolved during this fermentation is carbonic acid in a state of considerable purity.

This is an example of the change called "vinous fermentation"—a change to which all saccharine liquids are subject, provided they contain in solution azotized matter capable of putrefying, and are placed in circumstances favourable to that event. The azotized principle runs into spontaneous decay; it is slowly resolved into carbonic acid, ammonia, and other products, and the molecular disturbance thus produced in the decomposing body, or "ferment," is propagated to the sugar, the equilibrium of opposing attractions among the three elements of that substance is overthrown, while new and more stable compounds arise in place of that destroyed.

Conversion into alcohol is by no means the only change which sugar is susceptible of undergoing under the strange influence of a ferment, or decomposing azotized body. It may pass into an acid state, and give rise to one of the most curious organic acids existing, the lactic; or, lastly, it may be converted, partially, at least, into the sweet principle of manna, a substance which departs somewhat, as already hinted, from the sugar series. The *kind* of change induced, appears to depend altogether on the particular stage of decomposition of the ferment

itself, whose powers thus vary with the progress of its own decay.

These phenomena attract at the present moment a large share of attention, and they well deserve it; if the mysteries of vital chemistry are fated to be in any degree unravelled, it will probably be by the careful investigation of reactions such as these, which the ordinary laws of the science fail to explain. For the moment, it may be remarked, that nothing can place in a clearer light the very singular properties of these organic compounds—properties which, be it remembered, they owe to those of their truly Protean elements, carbon, hydrogen, oxygen, and nitrogen.

The decay of organic tissues, the bodies of plants and animals, is a process which has for its object not only the removal of useless matter, but its conversion into a form once more capable of supporting life. We shall discern, as we proceed, that reproduction and decay follow each other's footsteps throughout the whole system of Nature, and that the conditions of life and death are mutually involved in, and dependent upon, each other.

The great agent in all these actions is the free oxygen of the air, and the ultimate result is the transformation of the organic substance into such bodies as carbonic acid, water, carburetted hydrogen, ammonia, or nitric acid. The intermediate states, however, passed through, are very numerous and very imperfectly understood; still, there is every reason to think that they resemble those through which sugar passes, in the example before given, in

descending by a regular gradation of simplicity of form.

The constant, never-ceasing activity of free oxygen, is thus not only the mainspring, the motive-power, of life, in both animal and vegetable kingdoms, but it is the cleanser, the purifier, of earth and air and sea, from the defilements constantly poured upon, and into these latter, from the countless sources of poisonous contamination around us. Vapours of volatile substances, rich in hydrogen, the putrid effluvia of pestilence, become gradually destroyed by a real process of burning, more slowly, but not less completely, than in the flame of a furnace. The water of lakes and rivers, and of the great ocean itself, owes its sweetness to the same cause; the gas is dissolved, and penetrates to every part, quietly destroying in its progress every thing offensive. This is the explanation of the spontaneous purification which accumulations of foul water, freely exposed to the air, are well known to undergo; the impurities suffer oxidation, partly becoming destroyed, that is, converted into inorganic products, partly rendered quite insoluble, and so separated mechanically. These, however, in the end, disappear from continuance of the same cause, and suffer a similar fate.

It will be unnecessary to insist upon the obvious fact that these arrangements are not merely conducive to the welfare and comfort of all living creatures, but to their very existence.

Adult plants live upon the air; they get their

carbon from its carbonic acid, their hydrogen from its moisture, and their nitrogen from the little ammoniacal vapour which there exists. Plants thus feed upon inorganic substances, and the proof is not very difficult to give.

The simple fact of the decomposition of carbonic acid by green and living plants exposed to the light, is as old as the time of Dr. Priestley. Subsequent experimenters have shown that this effect takes place with equal facility, whether the gas be dissolved in water, and the plant immersed in the solution, or merely diffused through a quantity of atmospheric air in contact with its leaves: in both cases, the carbonic acid gradually disappears, and is replaced by free oxygen.

There are two conditions indispensable to the success of this experiment—namely, a sound and healthy condition of the leaf itself, and the presence of light. It is not necessary to have the direct solar beam; diffuse daylight is sufficient, although the action is not, in this case, so rapid and energetic as when aided by the bright rays of the sun.

In the absence of light these effects are exactly reversed; oxygen is withdrawn from the air and carbonic acid emitted, so that plants in the dark deteriorate the air in which they are confined.

The ultimate effect of living vegetables upon the atmosphere was for a long time a question among philosophers; it appeared doubtful to the minds of many, whether, in the case of an ordinary plant—a tree, for example, exposed under the open heaven to

the alternations of light and darkness, sunshine and gloom—the oxygen disengaged during the day, more than compensated the carbonic acid emitted in the night; whether, upon the whole, the effect of vegetation might not be null, or even hurtful, as regards the withdrawal of mephitic gas from the atmosphere, instead of being beneficial in the highest degree, as some supposed.

This question has now, to all appearance, been completely set at rest; experiments conducted in the most unexceptionable manner have fully shown, that a green, leafy plant, in full health and vigour, enclosed within an air-tight glass vessel, and frequently supplied with small quantities of carbonic acid during the space of many days, possesses the power of absorbing and decomposing that gas to such an extent, that the proportion of oxygen in the artificial atmosphere in which the plant is immersed may rise nearly ten per cent. above the normal quantity. It must be remembered, too, that in researches of this kind, plants are, of necessity, placed in somewhat unusual and disadvantageous circumstances, so that their powers are limited and crippled, and not to be compared to those they enjoy in their natural condition: they lose health, shrivel, and die, and then commences a putrefactive decomposition, the result of which is, invariably, the production of carbonic acid. It is to the neglect of this fact that the failures and discrepancies in the earlier experiments are due.

It is not easy to account for the uniform disengagement of carbonic acid in the absence of the

light-stimulus: it *may* be that the plant really respires, consuming oxygen, and generating carbonic acid like an animal, but to a far smaller extent. It may be, on the contrary, merely a consequence of a chemical change, an act of oxidation of the moist vegetable matter exposed to the air. There are arguments which might be adduced in favour of both these views; it is a point, however, the discussion of which may be, in the present instance, safely neglected, inasmuch as its decision, one way or the other, will not affect the general question of the influence of vegetables on the air.

So far all is satisfactory; we have the fullest reason to believe that plants are nourished by the carbonic acid of the atmosphere, which is absorbed directly by their leaves from the surrounding air, and also by their roots, when dissolved by rain-water; and, further, that the rapidity of this decomposition bears a direct relation to the intensity of the light.

In the tropics, for example, vegetation is wonderfully active, and this is due as much to the brighter sunshine, as to the more elevated temperature of these parts. There is no difficulty in obtaining in a stove or conservatory, an atmosphere as warm, and, if necessary, as moist as may be desired, and the plants of hot countries may be cultivated with a certain degree of success in such a situation, but they never exhibit the thriving and beautiful appearance, the deep green colour, characteristic of health, belonging to them in their natural state. We may substitute artificial warmth for that of the sun, but we cannot supply the place of its light.

The most valuable proof, however, of the principle laid down, is to be found in the observation of the manner in which forest trees are sustained and fed. It is easy to show that, instead of the earth in which they stand becoming exhausted of its carbon to supply their wants, it actually becomes enriched in that substance. The carbonaceous matter of the soil, the "humus" of the agricultural writers, is in fact nothing more than decaying vegetable matter which once had life; its quantity increases year by year, provided the ground be not disturbed and laid open to the oxidizing power of the air. We cannot attribute to *this* the office of supplying carbon to the trees; and except the carbonic acid of the air, there is no other source from whence it could be derived; so that, if positive experimental evidence on the subject did not exist, we should still be driven to the same conclusion.

In the case of cultivated plants, where the soil is constantly loosened by ploughing or digging, the humus may become useful as a source of carbonic acid by its decay, while the manure put upon the land is efficient, not so much on account of the carbon it contains, as of the nitrogen in the shape of ammonia, or of putrescible matter capable of becoming ammonia. Pure humus, decomposed woody fibre, is worth next to nothing, as those well know who have made the experiment.

If plants decompose carbonic acid, still more easily may we admit their power of decomposing water. This faculty is exerted in the production of each and every one of the proximate principles

which make up their solid frame. All these involve the separation of the elements of water as well as of those of carbonic acid. Even when oxygen and hydrogen exist in the ratio of the equivalents, it is necessary to suppose that this must occur. When resinous and oily principles, containing a large excess of hydrogen, are concerned, the case is still clearer.

Then for the nitrogen: although it cannot at present be positively proved that plants never absorb and fix the free nitrogen of the atmosphere, yet it can be rendered highly probable that they are destitute of this faculty. In the first place, the supposition is not necessary, from the occurrence of ammonia in the air, little as it is; and, in the second, the observation of the effects of ammoniacal compounds on vegetation gives the most convincing evidence of the value of ammonia in this respect. The azotized constituents of plants, more especially of *wild* plants, always bear but a very small proportion to those destitute of nitrogen, and for their production the natural supply of ammonia from the air is no doubt sufficient; but when we come to cultivate them, and to develop to an abnormal extent the parts of the system containing these azotized matters, the supply becomes insufficient, and we are accustomed to make up the deficiency by manure.

Allusion has already been made to the saline, inorganic matters of plants. These are, of course, supplied by the soil, which is thus often subject to exhaustion, unless means are taken to remedy the defect. It is difficult to explain the use of these

substances to the plant; but the regular and invariable manner in which they occur, and the sterility occasioned by their absence from the ground, concur in bearing testimony to their importance.

If we cannot exactly tell the use of these things to the plant itself, and feel difficulty in assigning a reason for the care with which they have been provided, and at the same time made indispensable, that difficulty vanishes at once when we take into consideration the end the plant itself has been destined to fulfil. The bones or shells of the animals they nourish are constructed in great part of inorganic matter. The circulating fluids contain abundance of soluble salts, which perform important functions in the body. These must be provided in proper quantity, and of the right kind, or the creature becomes diseased and dies. The earthy phosphates are as much wanted as the substance from which flesh is formed.

There is a curious class of vegetables, the physiology of which is at present but little understood, the fungi. These appear to differ altogether in many points from the green plants; their power of decomposing carbonic acid is denied; they are stated to vitiate the air instead of purifying it; light is not essential to them, and they thrive in circumstances of the most extraordinary kind. It is very possible that these beings may be constituted in a manner altogether different from ordinary plants; may feed on organic matter, like animals. They are, indeed, the scavengers of the vegetable kingdom, commis-

sioned to assist in the destruction and removal of once living but now lifeless forms.

These are some of the most prominent facts which a rapid survey of the vegetable world makes evident to us, but there are many other things which might be mentioned as giving proofs of design and adaptation of the most general and comprehensive character. To take a single one. Next to his food, man's most pressing want, even in the rudest state of society, is protection against cold. He employs fire for the purpose; that is to say, he takes means for developing violent chemical action between the elements of certain combustible substances and the oxygen of the air, and of availing himself of the heat thence disengaged. But does one man in a thousand, while enjoying the warmth of his fire, reflect for a single moment on the *combination* of circumstances to which his pleasure is due? Does he reflect on the very peculiar nature of the fuel provided for him in the forest and the field, or in the black bituminous coal, the relic of a vegetation now passed away? Does he pause for a moment to consider that the characteristic components of his blazing log, the carbon and the hydrogen, are the *only* elementary substances in existence fitted for the purpose; the only bodies whose products of combustion are of such a kind as to pass off in invisible and odourless form, to mingle in the air, and eventually to return again into the very same condition as that which has just been destroyed? It is most wonderful, when we reflect on these things, to observe

how much our physical happiness depends upon what some will call accidental circumstances. Is it by accident that carbonic acid is odourless, and harmless also, unless in considerable quantity, while the oxides of all other combustible substances, capable of existing in a gaseous state, are pungent and irritating, and insufferable in the smallest doses? A few hundred cubic inches of carbonic acid escaping into an apartment of small dimensions, so far from occasioning inconvenience, would be absolutely inappreciable. A thousandth part of that quantity of sulphurous acid would render the air irrespirable.

The greater number of combustible substances have fixed and solid oxides. What, it may be asked, would be the consequence if we had to burn phosphorus or zinc for fuel? Where would be our fireside comforts?—still more, where our manufactures? How should we reduce iron from the ore, or make porcelain or glass, or, in fact, perform any one of the thousand operations for which high heat may be required? For the purposes of artificial light, too, we have once more to trust to carbon and hydrogen. It would be difficult to find any thing else that would answer the purpose so well, at any rate. It is, in truth, among the common, every-day concerns of life that we find the most remarkable adaptations of all external nature to our wants. The philosopher may produce cases which arouse and startle by their novelty, but they can hardly surpass those that lie upon the very surface, open to the observation of all, and only to be neglected from the familiarity of unreflective enjoyment.

ANIMAL CHEMISTRY.

In order to convey to the mind of the reader a proper idea of the fundamental facts and doctrines of Animal Chemistry, and of the manner in which these bear upon the argument of design, it will be necessary to enter more into detail than the author has ventured to do in the preceding part of the essay.

The animal body is made up of certain solids and fluids in very unequal proportions. The solids determine the general figure and magnitude of the whole structure; the fluids communicate the rounded contour, softness, and pliancy, so essential to the well-being of the system. They are obviously mere watery solutions of various organic and inorganic substances, of which mention will be made almost immediately, and with them the solids are more or less distended and swollen, as their texture permits. By slow desiccation, this water may be got rid of, and the body sometimes reduced to less than a tenth of its original weight, or to little more than that of its bony skeleton. The mummies of Egypt and the New World are examples of this complete drying.

It will be proper to study, in succession, the chemical history of the chief compounds of the body;

of the blood, from which the body itself is built up; and, lastly, the nature of food and its functions. It must be premised, that the observations about to be made are to be understood as applying in their greatest force to the higher classes of animals, and especially to man; our knowledge of vital chemistry is, at present, almost entirely confined to these.

Among the proximate animal constituents there is a small group of three substances, related in a very close and intimate manner among themselves, and having properties in the highest degree remarkable and worthy of attentive study. These are—albumen, fibrin, and casein. The two first-named are diffused through the whole body; the third is found only in a special secretion. We may call them, for the sake of simplicity, the albuminous principles.

White of egg, or the clear "serum," or fluid part of the blood, may be taken as an example of albumen, as found in the body; perhaps the only condition in which it is ever so found. In this condition it presents the aspect of a glairy, adhesive liquid, of pale yellow colour and slightly saline taste, due to a quantity of common salt and chloride of potassium held by it in solution. If a piece of delicate reddened litmus paper be plunged into this liquid albumen, from whatever source derived, a blue tinge is immediately produced, indicative of the presence of an alkali. Further, it is in this state miscible with water in all proportions, and dries up, if spread upon a plate in a warm room, to a brittle, yellow,

gum-like mass, which, when put into warm water, swells, softens, and finally dissolves.

The alkaline condition of soluble albumen is especially deserving of notice. It is, in fact, to this free soda—for to such is the effect due—that the albumen itself owes its solubility; for if acetic acid be added, drop by drop, to serum, or diluted white of egg, until the alkaline reaction disappears, and then the whole suddenly mixed with a large quantity of pure cold water, the albumen is observed to separate in flocks, which, after a little repose, collect at the bottom of the vessel in which the experiment is made. These flocks are, in reality, pure albumen, which is thus seen to be insoluble in water when freed from the alkali with which it is always naturally associated. A very small quantity of potash or soda redissolves it, and the solution once more exhibits its usual characters.

Every one is, of course, familiar with the very curious change which white of egg undergoes on the application of heat—a change common to all liquids containing ordinary soluble albumen. The obvious alteration is a passage from the soluble to the insoluble state, or what is called "coagulation." No contrast can be greater than that between boiled and unboiled white of egg. Their chemical properties are also essentially different, and yet the chemist can detect no change of composition in the substance. It is true that the water extracts a little alkali and a trace of sulphuret of sodium, but the abstraction of these bodies is hardly sufficient to account for the change in question.

So far, therefore, as appearances at present go, the proximate animal principle, albumen, possesses the property of existing in two separate states without change of chemical composition ; and, further, the passage from the one to the other is effected by the mere agency of heat, the application of a temperature which need never exceed that of boiling water. This is the great characteristic property of albumen, by the aid of which it is distinguished from all other substances.

The second body of the group, fibrin, is found in two distinct conditions in the living animal ; in the blood, namely, where it is *dissolved*, perfectly fluid, and in the muscular flesh, of which it forms the characteristic ingredient. It is here solid and insoluble, or coagulated.

When a thin slice of muscle is washed in cold water until perfectly white, it is seen to consist of a stringy-looking substance, which is the fibrin itself, traversed in all directions by blood-vessels, and nerves, and membranous matter. It may be extracted from blood in a much purer condition by strongly agitating that fluid, in its recent and yet warm state, with a bundle of twigs; the fibrin attaches itself to the extremities of these latter in the shape of long elastic strings, which by patient washing may be entirely freed from colour. It is not, however, yet pure, inasmuch as it still contains fat in considerable quantity. By drying, it shrinks prodigiously in volume, becomes transparent and horny, and in that state may be preserved indefinitely.

The experiment just described serves to exhibit, in

a very characteristic manner, the chief peculiarity of the substance under discussion ; its capability of assuming the solid form spontaneously, so soon as it is withdrawn from the influence of life. Owing to this circumstance, little or nothing is known of the other properties of fibrin in the soluble state ; all the experiments of chemists have of necessity been made upon that which has undergone coagulation.

The third substance, casein, is found only in milk, where it exists in a state of perfect solution, owing, like albumen, its solubility to a small quantity of alkali. Unlike the substance just mentioned, however, casein is not coagulated by heat ; milk may, as is well known, be boiled without any change of the kind. The addition of a little acid, of almost any description, determines the precipitation of the casein by withdrawing the alkali which held it in solution ; and it is interesting to observe the very small amount of acid required for this purpose when the reaction is aided by a gentle heat.

The manufacture of cheese depends upon this property of casein, which appears to have been, until quite recently, much misunderstood. When a piece of the lining membrane of the stomach of an animal, more particularly of a young animal, as a calf, is cleansed by slight washing in cold water, plunged into a large mass of milk, and then the temperature of the whole slowly raised to about 120° or a little higher, it is observed that, at a particular moment, the milk undergoes coagulation of a very complete kind ; it separates into solid, white, opaque " curd," and thin, pale-coloured,

translucent "whey;" the former consisting chiefly of casein and butter, and the latter of water, holding in solution most of the saline components of the milk, together with the substance to which it owes its sweetness; this is the "milk-sugar" of chemical writers;—a body to which reference will again be made. For the purpose of preparing cheese, the coagulum so produced is drained, mixed with salt, and sometimes other condiments, and after various manipulations, the principal object of which is to communicate consistence and form, and get rid of superfluous moisture, the cheese is suffered to remain several months in a cool situation, where it undergoes that particular kind of putrefactive change upon which its flavour and value depend.

The coagulation of milk, under the influence of a simple wet membrane, is a phenomenon so remarkable, and so difficult to explain, that we need not wonder at the attention it has excited. Experiments have been made with a view of ascertaining the effect on the membrane itself. Among these, a very curious one is due to Berzelius: he relates that he took a bit of the lining of a calf's stomach, washed it clean, dried it as completely as possible, weighed it carefully, put it into eighteen hundred times its weight of milk, and heated the whole to 120° F. After some little time, coagulation was complete. He then removed the membrane, washed, dried, and once more weighed it; the loss amounted to rather more than $\frac{1}{2}$ of the whole. According to this experiment, one part of the active matter dis-

solved from the membrane had coagulated about thirty thousand of milk.

The researches of several French philosophers on the lactic acid fermentation, and the still more recent experiments from the Giessen laboratory, on the condition of casein in milk, permit a tolerably satisfactory explanation of this singular change, by linking it to a multitude of others, in which a common principle is involved. It has been shown that the sugar of milk, a substance differing very considerably in properties from both cane and grape sugar, is peculiarly prone, under favourable circumstances, to pass into lactic acid by appropriating the elements of water.* The presence of a ferment, or decomposing azotized body, is essential to this change, as to all of like nature, but the origin of the ferment itself is a matter of perfect indifference; it may come from either the vegetable or the animal kingdom; it matters not, provided only that it be in the *proper stage of decay* for developing the lactic acid fermentation. Now it appears that an animal membrane such as that adverted to, removed from the body and left a short time in contact with water, is in reality very frequently in this particular condition. Decay commences the moment life is extinct, long before any thing like putrescence is perceptible, and the result of this decay, insensible to all ordinary means of observation, is the acquisition by the decomposing body of the power of becoming a lactic acid ferment. A piece of "rennet" is put into a

* See Appendix, No. 2.

quantity of fresh milk; it immediately begins to exert its fermentive power upon the milk-sugar present. In the course of a very short time, enough lactic acid is formed under its influence to saturate the alkali which holds the casein in solution, whereupon the base is, by the aid of a little heat, entirely withdrawn by the acid from the casein, and the latter rendered in consequence insoluble.

The quantity of lactic acid really required for bringing about this decomposition is extremely minute; a mere trace is enough. The casein itself, too, may, if a little time be allowed, act the part of ferment to the sugar, and give rise to lactic acid. There is no lactic acid in pure, fresh milk; after a few hours it makes its appearance, however, and continues to increase in quantity until enough has been generated to coagulate the casein, even in the cold, and to communicate to the whole a powerfully acid re-action. Casein, then, is sufficiently characterized by being precipitated from its solution by feeble acids which do not coagulate albumen, and by not being coagulable by the aid of heat.

The chemical composition of these three bodies —albumen, fibrin, and casein—has been made the subject of many careful inquiries. It is only within the last few years that the practical analysis of organic substances has been in a state of sufficient advancement to be applicable to investigations of such a difficult and delicate nature as those which have for their object the determination of the exact proportions in which the elements of bodies of this kind are associated. Step by step, however, ana-

lytical processes have been improved, both in accuracy and ease of execution, until very little has been left to desire on this point.

M. Mulder, of Amsterdam, has the distinguished honour of having made the first correct and consistent analysis of a great number of complex animal principles, including those described; the difficulties he had to encounter in this task were very great, and the manner in which they were surmounted reflects the highest credit on his sagacity and skill. Many of the results of Mulder's researches have been confirmed by the subsequent experiments of Scherer, Dr. Bence Jones, and others.

It appears that albumen and fibrin are compounds of carbon, hydrogen, nitrogen, oxygen, sulphur, and phosphorus; casein contains, it is said, but five elements, phosphorus being absent. The most remarkable feature of the case, however, is the absolute identity of composition of these three bodies as respects the carbon, hydrogen, oxygen, and nitrogen; the only difference is to be found in the sulphur and phosphorus, which bear, it must be remarked, an exceeding small proportion to the other constituents.

The extreme importance of this discovery will probably be apparent in some measure even now. It will explain, in the simplest and most beautiful way conceivable, the fact which we know to occur of the constant transmutation in the animal system of one of these substances into the other; it will show how easily the milk of the mother becomes the flesh of the offspring, and with what simple change the

albumen of the food of the adult animal, rendered soluble by digestion, and absorbed from the alimentary canal by an apparatus provided for the purpose, becomes in part changed to fibrin by the time it finds its way into the veins to form new blood.

It is true that the identity of composition of the albuminous principles has since been called in question by M. Dumas, who has published a very elaborate series of analyses, in which certain differences are pointed out, apparently too large and too constant to be considered the consequence of mere errors of experiment. The subject thus imperatively demands re-examination, as it is too important to be left in doubt.

When either albumen, fibrin, or casein is dissolved in dilute caustic alkali, and the solution precipitated by a slight excess of acid, a large quantity of white, flocculent matter separates, which may be very easily collected upon a filter, washed, dried, and subjected to examination. This body is the "Protein" of Mulder; it is the same in properties from all three sources, while analysis shows it to contain carbon, hydrogen, oxygen, and nitrogen, exactly in the same proportions as we have them in fibrin, albumen, and casein.

This most beautiful experiment may receive at least two interpretations. We may suppose, with the discoverer, that the new substance, the protein, is really the common fundamental basis of the three albuminous principles, which it forms by uniting with certain small quantities of sulphur and phosphorus, or sulphur alone, and which latter bodies

become separated by the alkali, and retained in solution when the protein is precipitated by an acid; or we may, on the other hand, imagine that the protein is a product of the action of the base, generated, in short, under its influence, in the same way as stearic acid and glycerine may arise from a neutral fat under similar circumstances, there not being a tittle of evidence to show that either of these last-named bodies pre-exist in the fat itself. Whichever view be adopted—and it is a thing of no moment—we cannot fail to be struck with the remarkable support afforded by these experiments to the doctrine of the partial identity of composition of the protein-giving principles. This must suffice, although much more might be said, for the albuminous group.

The membranous and cartilaginous tissues, the "cellular substance" of the body, all those portions which dissolve in boiling water and furnish a jelly on cooling, must now be noticed. A distinction is drawn between membrane and cartilage, on the ground that the one gives by boiling ordinary gelatine, and the latter a substance differing somewhat from gelatine, to which the term "chondrin" has been applied.

Gelatine, the properties of which in a state of some purity are to a certain extent generally known from its wide-spread applications, does not, it seems, pre-exist in the animal body; if it did, we should, no doubt, find it in the blood, which is not the case, from its ready solubility in warm water. It is believed to be produced by a specific chemical change

of one or other of the albuminous principles by the agency of oxygen drawn from the air. One of the many possible representations of the nature of this change is given at the end of the volume, which, it must be remembered, is merely conjectural, as all such representations at present must be, from want of sufficient experimental evidence to give them a higher claim to attention.

The substance of the brain and nerves appears to be principally albumen, in a peculiar state, associated with certain remarkable fatty substances, one of which is said to contain a very large amount of unoxidized phosphorus; and, lastly, the bones, and even the teeth, are constructed of cartilaginous material, stiffened out and made hard and rigid by earthy salts, principally phosphate of lime.

Such are the chief components of the animal body.

Now it does not require much observation to convince us that, so long as life continues, a perpetual destruction, a never-ceasing waste of all parts of the body is constantly going on. From the first moment of our being to the termination of our days, there is never, for a single instant, such a thing as permanence of state. The various secretions of the body are always in progress; oxygen is absorbed into the system at each inspiration; water and carbonic acid are thrown off every time the lungs collapse; the skin abandons, too, its quota of these substances, which pass away in an invisible form, and elude ordinary observation; and what is still more remarkable, the manifestations of living

power, the amount of nervous energy possessed by the individual, is connected in some mysterious way with this very waste and degradation itself. The exertion of muscular power, the very exercise of the mind itself, are, so far as we can judge, as intimately bound up with change of matter, as the evolution of electricity in the voltaic pile is with the chemical action upon the metal with which the instrument is constructed.

To compensate these continual losses, so destructive to the body, and yet so indispensable to life itself, a formative power, like that possessed by plants, has been communicated to the system, by virtue of which repair is constantly made, with the assistance of material furnished by the blood, which thus not only becomes the channel by which decayed and altered matter is withdrawn from the body, but the very store-house and reservoir of nourishment and support to every part of the structure.

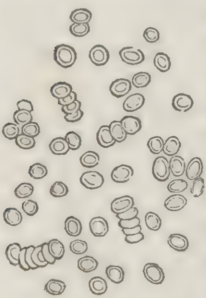
It is obvious, however, that the efficiency of the blood for this most important purpose depends altogether on the maintenance of its proper chemical nature; on the constant replacement from without, in the shape of appropriate food, of the materials abstracted from it in the renewal of the bodily frame, and in the exercise of other functions, particularly that of respiration. It is only in this way, *by previously becoming blood*, that food can be of any use; it must be capable of sanguification, or it cannot fulfil the duties required from it.

The chemical history of the blood is exceedingly

curious and interesting so far as it is understood. To the naked eye, it presents the appearance of a homogeneous red, or dark purplish liquid, somewhat viscid, and having a density considerably above that of water. It has a saline and peculiar taste, and a specific odour, which it very speedily loses.

When examined by a microscope of great power, blood is seen to consist of multitudes of little round red bodies, floating about in a nearly colourless liquid; these are the "blood-globules," or "corpuscles" of the physiologists, and to their number and minuteness the uniform red appearance of the whole is obviously due.

There has been a great deal of dispute about the figure and structure of these corpuscles; the prevalent opinion seems to be that they are disc-shaped, round, and flat, with a depression in the centre, which in some positions of the light assumes the



appearance of a nucleus or little transparent bead. It is probable, however, that this is an optical illusion; it is only seen when transmitted light is employed. By reflected light the thickened edges of the corpuscles are very evident, and no nucleus can be seen in the centre; they look like the steel rings of a piece of mail.

It may seem strange to some that doubt and uncertainty can exist about a simple matter of fact; but these bodies are very minute. In man they are said to vary from $\frac{1}{6000}$th to $\frac{1}{3500}$th of an inch in diame-

ter, and in some animals they are even smaller. Microscopic investigations are beset with fallacies, and in the most careful and experienced hands often give equivocal and contradictory results.

The blood contains, in addition to the corpuscles above described, great numbers of colourless globules, of still smaller dimensions, the nature of which is very little understood. Some of these are certainly, however, composed of fat.

When a portion of blood is drawn from a living animal into a shallow vessel, and left to itself for some hours, it undergoes spontaneous coagulation in a very complete manner; it separates into a dark red solid clot, and into a pale-coloured, slimy, saline, and distinctly alkaline liquid which floats above. This has already been mentioned as the chief depository of albumen in the body. The effect described is obviously caused by the solidification of the fibrin, which, although constituting, when dry, a very small portion of the whole, in the bulky and swollen condition in which it separates, is voluminous enough to entangle in its network of fibres the whole of the colouring particles, thus carried down, and mechanically separated from the fluid which held them in suspension. The production of the coagulum in blood is not the result of any formation of acid, as in the case of milk, but arises simply from the distinguishing peculiarity of fibrin before described.

If the clot be drained as much as possible from serum, by contact with bibulous paper, and then put into water, the whole of the colouring matter dissolves, if time be allowed, and the white filaments

of fibrin left untouched subside to the bottom of the vessel. The solution so obtained possesses a magnificent crimson-red colour, and is found to contain a substance which very closely resembles an ordinary dye-stuff, like that of cochineal or logwood. It gives coloured precipitate or "lakes," with alumina and oxide of tin, and other substances used by the dyer to fix his colours upon cloth, and is altogether a very curious compound. Unfortunately, it is one very difficult to study, from its great instability; it begins to decompose and change its hue after a very short time: moreover, it is associated with some albumen still remaining behind, the separation of which seems almost impossible.

The red colouring matter of the blood is thus merely suspended in the serum; not dissolved. In water, the corpuscles break up and disappear; but in a strong saline solution, or a highly albuminous liquid, they retain their integrity. The serum is a liquid of this kind, or, rather, it is both saline and albuminous, and in it consequently the little bodies in question float about uninjured. Its state of dilution, however, is such as to approach very near the point at which solution would occur; for if a little water be added, and the density of the liquid still further reduced, the red discs begin to be attacked. Now there can be no doubt but that the blood corpuscles, in a perfect and entire state, are in some way intimately connected with the vital functions; what their office is, cannot at the present moment be positively stated, although a conjecture on the subject exists, and will be almost immediately mentioned.

Their constant and uniform occurrence and peculiar organization — for the term may safely be applied — sufficiently indicate their importance. An adjustment, therefore, has evidently been made of the density of the blood-serum, and the amount of solid matter contained in it, to the peculiar properties of the corpuscles, in such a manner as to secure the integrity of these latter, and at the same time retain sufficient thinness and fluidity for the fulfilment of the numerous duties required from it.

The red colouring matter has a composition approximating to that of the albuminous principles, which it resembles in many other respects. It contains, however, in addition to the elements of these bodies, a component of a very peculiar nature, which is found nowhere else in the system: this is the metal iron. The proportion of iron is not a mere trace, it makes up more than a twentieth of the weight of the dry red substance. We cannot for a moment suppose it to be accidental.

The mere presence of iron in blood is easily demonstrated. If a portion of that fluid be evaporated to dryness and carbonized by a red heat in a crucible, a black, spongy mass of coal will be obtained, from which dilute acids extract abundance of oxide of iron; or, still more simply, by acting with a somewhat stronger acid upon dried clot, which readily yields iron in this way. It has been usually stated that the metal exists in blood in a very peculiar state, a state in which it is not acted upon by ordinary reagents; but this is, to say the least, doubtful; the blood is alkaline, and alkalinity is incompatible with

more than one of the most characteristic tests for iron. There are many organic substances, which, added to a salt of iron, altogether prevent its precipitation by an alkali. Some of the vegetable acids have this property. So that the mere fact of the alkaline soluble condition is of itself no proof that the metal is not in the state of oxide.

It is not easy to understand how this red matter, or "hematosin," directly contributes to the building up of the animal framework; no organ or part of the body contains iron in appreciable quantity as an essential component; and, besides, it seems unnecessary. We do not want it for this purpose, since the blood contains, in a soluble state, abundance both of albumen and fibrin,—bodies appertaining to a class from which alone, so far as appearance goes, the various tissues and organs of the body have their origin. Yet this substance must have some specific office, because it is constantly observed that, in those diseased states of the body in which the red particles are deficient in quantity, the functions of life are languidly and imperfectly performed; and, still further, that this state is improved, and health amended, by the administration in medicine of salts of iron.

Various ideas have been entertained on this subject by those devoted to physiological inquiries. One only of these requires mention, in the present instance, namely, that of Professor Liebig, who has ventured to assign to the blood-corpuscles an office no less important than that of serving as carriers of oxygen from the lungs to all parts of the body; a power which he considers them to enjoy in virtue of

the iron they contain. The following is a sketch of this very beautiful and ingenious hypothesis.

The metal, iron, is known to form two* compounds with oxygen:—a protoxide and peroxide; the latter containing one half as much more oxygen as the former. These two bodies, moreover, very easily pass, under favourable circumstances, the one into the other. If, for example, a salt of the protoxide be mixed with caustic alkali in excess, the precipitated proto-hydrate, at first nearly white, after passing very quickly through various tints of green, becomes foxy-red, or rust-coloured, and, if examined, is found to be hydrate of the peroxide. This change is caused simply by absorption of oxygen from the air; it commences at the surface of the mass, and gradually creeps downwards until the alteration is complete. Again, peroxide of iron, in contact with many organic substances, is, with but little aid from heat, deprived of a third of its oxygen, and thus reduced to the condition of protoxide; and these changes may go on indefinitely, the metal being alternately in either state, as the oxidizing or reducing influences around it prevail. This is a property of iron which exists to the same extent in no other metal.

In the body there are two distinct kinds of blood; that of the veins, which is dark claret-coloured, sometimes approaching to black, and that of the arteries, which is always bright red. It is generally

* A third has quite recently been discovered, but this does not interfere with the argument.

well known, also, that the change from the venous to the arterial condition is effected in the blood during its passage through the minute capillary tubes which ramify over the surface of each air-cell of the lungs. This alteration, of which evidence is given by the immediate change of colour, is certainly due to the absorption of oxygen from without, and escape of carbonic acid from within. These gases are conveyed through the thin wet membrane, in virtue of their solubility in water, and not by any vital action; it is an effect always observed with porous bodies in general when thoroughly filled with liquid. The opposite change, that from arterial blood to venous, is also known to occur in those equally minute vessels or passages which unite the ultimate subdivisions of the veins and arteries, and in which, whatever be their nature, all the great functions of life are certainly carried on.

Such are the acknowledged facts. The use of the iron is thus explained:—In the bright red aerated blood, the iron exists in the state of peroxide, its highest degree of oxidation. So long as it travels through the larger vessels this state is maintained. It is in contact with de-oxidizing matter it is true, but then the whole mass is loaded with dissolved oxygen gas taken up in the lungs, which prevents any thing like de-oxidation. By and by, however, by the time the blood reaches the smaller branches of the general arterial system, much of this free oxygen has disappeared; and at last, when it gets into the capillaries themselves, the reducing power, appetite for oxygen, or combustibility of the matter of the

various parts and organs with which it is in contact, becomes so high and energetic, that the loosely combined oxygen is abstracted from the peroxide of iron, and that substance reduced to protoxide, beyond which, of course, it cannot go. The organic tissues thus oxidized or burned produce carbonic acid, which saturates the protoxide of iron, so that we have it in the venous blood in the state of carbonate.

Now, moist proto-carbonate of iron exposed to the air, readily gives up its carbonic acid, absorbs oxygen, and passes to peroxide. This takes place in the lungs, and accounts, in some measure at least, for the large amount of that gas in the expired air.

Much of the oxygen which finds its way into the system is, as just hinted, undoubtedly taken up by the serum itself, in consequence of its solvent power. The greater part of this, but not the whole, gets converted into carbonic acid by the time the blood reaches the great venous trunks, and afterwards conveyed into the air by the false diffusion before spoken of.

This is certainly a very beautiful theory of the use of the iron. Whether it be true or not is another question;—a question which cannot, at present, be solved. Our means of experiment are very far from permitting the determination of such a problem one way or the other. On any supposition, however, a great part of the sketch given must be true. The oxidation, the burning of the substance of the body; in other words, the change of matter indispensable to every vital movement; the combustion of carbon and nitrogen, in short, in

the blood—takes place not in the lungs, but in the capillary vessels of the whole body. Here is the fire-chamber where the fuel is consumed, which is destined to set in motion the whole machinery of life.

The term furnace is used advisedly. It is with premeditation and choice of terms that the capillary system is compared to a fire-place. We must disconnect the idea of combustion, in the larger sense in which it is here employed, from that of flame or ignition, where the heat evolved is intense. There is no chemical doctrine more probable, but at the same time, unfortunately, more difficult of demonstration, than that which declares the constancy of the relation between chemical action and its calorific effects. There is every reason to believe that the same amount of chemical force always develops the same quantity of heat. Whether that heat be very gentle or very intense, is simply an affair of time. A piece of iron, slowly rusting to its centre in the atmosphere, develops, during its oxidation, as much heat as an equal weight of the metal in that minutely divided state in which it burns on contact with air. In the one case, the action is distributed, as it were, over a great length of time; in the other, it is completed in a moment. As much heat however, has, without doubt, been evolved in the one instance as in the other, only it has been dissipated and lost as fast as it was produced, and never acquired sufficient intensity to attract attention. The beautifully constant relations of number and quantity between chemical and elec-

trical, between electrical and magnetic forces, absolutely forbid any other supposition, as at variance with all the great laws of the material world which science has made known to us.

Carbon and hydrogen are burned in the blood, and this to an extent which will strike with surprise, and at first, incredulity, those unaccustomed to such considerations. Many ounces of carbon are, in every individual, daily rejected from the lungs as carbonic acid. It is impossible that combustible matter can thus be disposed of without the evolution of a vast amount of heat; as much heat, in fact, as if it had been burned in a fire-grate. This heat is manifest in the elevation of temperature which the animal frame always possesses above that of the surrounding medium; an elevation of temperature always in direct proportion to the amount of nervous and muscular energy of the animal, and to the vigor of its respiration, but never in any single case altogether absent.

The internal capillary combustion is the source of animal heat.

Thus much for the body. Every part where blood-vessels are to be found; every part where nervous influence is perceptible; every organ, every tissue; muscle, and brain, and nerve, and membrane, waste away like a burning taper, consume to air and ashes, and pass from the system, rejected and useless; and where no means are at hand for repairing these daily and hourly losses, the individual perishes—dies more slowly, but not less surely, than by a blazing pile. He is, to the very

letter, burned to death at a low temperature; the various constituents of the body give way in succession; first, the fat disappears; this is the most combustible, but at the same time the least essential; it is sacrificed; then the muscles shrink, and soften, and decay. At last the substance of the brain becomes attacked, and madness and death close the scene.

This is starvation.

Among the most beautiful results of organic chemistry must certainly be placed those which instruct us in the nature and functions of the food. Much yet remains to be done before the subject can be considered at all complete, and some of the most interesting results are yet disputed; but still enough has been effected to shadow out certain general principles in the highest degree worthy of attention. The first, most important, and, perhaps, best established of these principles, admits of being laid down in the form of a definite proposition. It is to the following effect:—

> Those substances only are capable of being employed in the renewal and repair of the body, which have the same chemical composition as the body itself, or, which comes to the same thing, as the blood, out of which the body is constructed.

There are but three proximate organic principles yet known which come within these terms; those, namely, already described—albumen, fibrin, and casein; these only have the power of reproducing

blood, and these only can afford nourishment and support, in the strict sense of the term.

It is not meant that these bodies alone, in a state of great purity, are all that can be required for the due maintenance of the vital powers; on the contrary, the experiment, cruel as it is, has been tried repeatedly, and always with a negative result. Certain non-azotized bodies seem to be essential—such as fat, or some substitute for fat, always present in natural food. These alone, are still less capable of supporting life than the unmixed albuminous principles. Although such bodies are often but sparingly furnished, they are always to be found. There are other substances, too, required by the animal, which, in small quantities, are as essential to its well-being as the inorganic salts of the vegetable kingdom are to the plant. Phosphates, ferruginous matter, compounds of potash, soda, and lime, and perhaps other things, are required. An animal can no more live on albumen alone than a plant on carbonic acid alone; in fact, there is a very close resemblance between the two cases.

The process of nutrition in animals that feed on flesh is simple in the extreme; the food consumed is identical, in every respect, with the body for whose nourishment it is designed. Arrived in the stomach, it undergoes simple solution in the slightly acid secretion of that organ, and then, as it passes through the short and simple alimentary canal of these creatures, it gets almost entirely absorbed, and at once carried into the blood, nothing being rejected but the comminuted bones and hair, and other insoluble rel-

ics of the prey. The flesh of the animal devoured, becomes by mere transposition, part and parcel of that of its devourer.

So far all is simple and clear enough; the majority of animals, however, do not live upon flesh, but are, on the contrary, exclusively vegetable feeders. We require to see how the law applies in this case.

It is here that the unspeakable importance and value of the vegetable albuminous principles, referred to in an earlier part of this volume, becomes manifest. These bodies are diffused throughout the whole vegetable creation; not a plant exists which does not contain one or other of them. A few examples may be cited; it would be easy to extend their number almost indefinitely.

The grain of the cereals is rich in azotized matter of this kind, which may be separated by an exceedingly simple mechanical process. The meal is mixed with water to a paste and patiently washed, either in the hand or on a fine metallic sieve, until the whole of the starch has been carried away, and the liquid runs clear; there then remains behind an adhesive, elastic substance, long known under the name of "gluten." If this gluten be now boiled with strong alcohol, a small quantity of a peculiar sticky matter is dissolved out, together with some fat, and there remains a white, stringy-looking body, which, when carefully examined, is found to be absolutely identical in every respect, both in properties and composition, with the fibrin of the animal frame.

This vegetable fibrin is found in wheat-flour to the

extent of eight or ten per cent., and is the principal cause of the high value of wheaten bread as an article of food.

Again, if the juice of any green plant be taken, filtered to render it clear, and then exposed to heat, a substance separates in little flocks, which, when collected, dried, and boiled in ether to remove certain impurities soluble in that liquid, exhibits all the characters and composition of boiled white of egg. This is vegetable albumen, and it is to be found throughout the whole vegetable world.

Once more: it has been discovered that beans and almonds, and a great variety of seeds, often contain, in addition to one or both of the above-mentioned substances, a third, which is identified with animal casein.

There is no difficulty, then, in understanding how it is that animals live upon plants; these plants already contain, ready-formed, the principal materials of their bodies, which only require to be separated and brought into a soluble state to become blood. The function of nutrition is in every respect the same as in those creatures that live upon flesh.

Now, however, comes a very remarkable difference between the food of these animals and that of the carnivora, which consists of pure flesh and merely a little fat. Vegetables contain but a comparatively small portion of azotized matter; the great bulk of their substance is made up of woody-fibre, or starch, or gum, or something of the kind, destitute of nitrogen. These things cannot form blood;—cannot, directly at least, nourish the body.

In a flesh-eating animal the destruction of the tissues of the body is very rapid indeed, as the character of the excretions fully demonstrates; the temperature of the body is in a great measure kept up, and vitality maintained, by the burning of flesh and nerve. This rapid decay is, however, compensated, and equilibrium maintained, by an abundant supply of highly azotized food, capable of rapid and complete assimilation.

Such is not the case in the graminivora; the supply of these protein compounds is but slender, and requires to be economized to the utmost. They constitute a fuel too costly to be burned to any great extent. We find, however, associated with these azotized matters, a very large quantity of saccharine or starchy substances, which disappear in the body completely. Taking all these things into account, the conclusion drawn by Liebig appears perfectly inevitable—namely, that the non-nitrogenous constituents of the food of these animals, whether it be starch, or sugar, or fat in any shape, is exclusively employed in the generation of animal heat—in economizing, in short, the more essential components of the body by becoming burned in their place.

We thus get a division of the whole food into two distinct classes of substances—those, namely, which are devoted to the repair and nutriment of the body, and those whose duty it is to furnish animal heat by their combustion in the blood. Among the former, called by Liebig, "plastic elements of nutrition," we find—

Vegetable fibrin,
Vegetable albumen,
Vegetable casein,
Animal flesh and blood;

and among the latter, or "elements of respiration"—

Fat,	Grape-sugar,
Starch,	Milk-sugar,
Gum,	Mucilage,
Cane-sugar,	Wine, beer, spirits.

These constitute fuel-food, and are of no other use.

A few remarks on the quantity of carbon actually consumed in one day in the body of man, and of one or two of the larger quadrupeds, will suffice to terminate this general sketch of the subject.

Two distinct and wholly dissimilar methods of inquiry have been followed in this investigation, and both are unfortunately attended with great practical difficulties of execution. The results, nevertheless, tally sufficiently well with each, and induce us to place considerable confidence in their accuracy.

The first method—that followed by all the earlier experimenters—consists in determining directly, by careful analysis of the expired air, the quantity of carbonic acid discharged from the lungs in a given time; then, if the disengagement of gas be supposed uniform, the quantity daily produced admits of easy calculation.

There are several important fallacies, however, in this plan. In the first place, breathing conducted through a tube connected with a gas-holder, which

was the system generally practised, must be very different from breathing in the open air. The inspirations and expirations are much deeper when the attention is directed to the process. It is not unlikely that this error may be, to a considerable extent, compensated by their diminished frequency, and the ultimate result thus rendered more correct than the process seemed to promise. Again, the production of carbonic acid is by no means uniform throughout the day. Dr. Prout* found it to vary considerably at different times, being greatest at noon, during gentle exercise, and least of all in the depth of sleep. This is precisely what we should expect to find from theoretical views, and the fact has since received experimental corroboration.

The lungs constitute, it is true, by very far the most important channel by which carbonic acid escapes from the body. There is another, notwithstanding, in the skin, which, in these experiments, is altogether neglected. The whole surface of the body disengages the gas in question ; a fact which must always be taken into account.

There have been many able experimenters engaged on this subject. In the Philosophical Transactions for 1808, will be found, for example, an exceedingly interesting memoir by Messrs. Allen and Pepys. The experiments were made at the Royal Institution. It was concluded, that " a middle-sized man, aged about thirty-eight years, and whose pulse is 70 on an average, gives off 302 cubic inches of carbonic acid in 11 minutes ; and supposing the production

* Quoted by Berzelius—Lehrbuch, 9, p. 125.

uniform for 24 hours, the total quantity in that period would be 39,534 cubic inches."

Now, 39,534 cubic inches of carbonic acid weigh 18,683 grains, and contain 5166 grains of carbon, or 10·7 ounces troy.

The estimate of Sir H. Davy* agrees very closely with the preceding--namely, 26·6 cubic inches per minute, or 38,304 cubic inches in the day. This quantity will weigh 18,102 grains, and contain 5006 grains of carbon, or 10·4 ounces troy.

The close coincidence of these experiments both with each other, and also with some of more recent date in which the sources of error adverted to were guarded against, is very remarkable.

Dr. Scharling has lately put in practice a modification of the same method. The person experimented upon was inclosed in an air-tight wooden chest, sufficiently capacious to enable him to remain a considerable time without inconvenience, and follow a variety of occupations, and even sleep. A glass window was fitted to the chest. By suitable contrivances a slow but constant supply of pure air, freed from carbonic acid, was passed into the apparatus during the whole period of each experiment, and at its exit conducted through a strong solution of caustic potash contained in an ordinary Liebig's apparatus, by which the proportion of the gas thus carried away was easily estimated. Lastly, the air of the chest itself was carefully analyzed at the commencement and termination of each experiment, and

* Memoirs, 3, p. 255.

corrections duly made in the calculated results for alterations of pressure and temperature.

The usual duration of an experiment was about an hour. They were made upon a variety of persons, and at various periods of the day and night, in the hope of obviating the errors arising from changes in the state of the body.

The variations in the quantity of carbonic acid given off were very considerable. During sleep, and when fasting, it was at its minimum, and after a meal invariably highest. Children exhaled more carbonic acid, in proportion to their weight, than adults. The following are Dr. Scharling's general conclusions respecting the quantities of carbon actually disengaged, in the course of twenty-four hours, by each of the six persons undermentioned, upon whom the experiments were made. It is assumed, that, in the case of the children, nine hours were passed in sleep, and in that of the adults seven hours:

1. A man, 35 years old, weighing 131 Danish lbs., gave off in the time mentioned 3386 grains of carbon=7.05 oz. troy.
2. A young man of 16, weight 115½ lbs. 3462 grs.=7·21 oz.
3. A soldier, 28 years old, weight 164 lbs. 3698 grs.=7·07 oz.
4. A girl of 19, weighing 111½ lbs. 2559 grs.=5·33 oz.
5. A boy of 9¾ years, weight 44 lbs. 2054 grs.=4·28 oz.
6. A girl of 10 years, weight 46 lbs. 1935 grs.=4·03 oz.*

Several years ago, M. Boussingault devised, and put into practice with great ingenuity, a form of experiment for the purpose of solving a very im-

* Annalen der Chemie und Pharmacie, 45, p. 214.

portant problem in agriculture science, which he afterwards applied to animal physiology.

The problem was to determine the relative quantities of food furnished to cultivated plants by the earth and by the air, and the plan proposed for its solution was as follows:—During the whole time of one rotation, a period extending over five years, an exact account was kept of the quantity and chemical composition of the manures spread upon a marked extent of ground, and of the different crops raised from it, using all precautions to prevent error from varying quantities of water in the different substances examined, and conducting the analyses with great care. At the end of the period referred to, on comparing the total amount of carbon, hydrogen, nitrogen, oxygen, and inorganic matters contained in the plants raised, with that furnished to the land in the shape of manure, it became easy to see how much of these bodies the earth and the air had respectively furnished. A simple subtraction would give the information required.

Just in the same way, if it be required to determine the quantity of carbon and hydrogen daily burned to carbonic acid and water in the body of an animal, it is only necessary to compare by analysis the proportion of those substances given in the food with that contained in the excretions of the animal itself. The difference between these will obviously represent the quantity consumed in respiration.

M. Boussingault* experimented on a cow and a horse; his principal object at the time was to settle

* Annales de Chimie et de Physique, lxxi., p. 113.

the disputed point of the absorption or non-absorption of nitrogen from the air by animals, which he to a great extent effected, by showing that in an animal so supplied with food that its weight remains for a long time unchanged, the nitrogen contained in that food always exceeds that voided in the excretions. At the same time an opportunity was afforded for examining the amount of carbon lost, by the aid of a similar comparison.

It was found that in twenty-four hours the cow consumed in respiration the enormous quantity of seventy ounces of carbon, and the horse seventy-seven ounces. Professor Liebig has lately applied Boussingault's method to the human subject. His mean result indicates an expenditure of about fourteen ounces of carbon daily, for well-fed, healthy men employed in labour in the open air, as soldiers: the amount is much smaller in those who lead a depressed or sedentary life.

The diet-tables of the Royal Navy furnish the means of making an approximation to the quantity of carbon required for the respiratory process, in circumstances extremely favourable to its activity. As no very accurate determination has been made of the per-centage of carbon in the different articles, the numbers given must not be looked upon as absolutely correct; it is probable, however, that they are not far from the truth.

TABLE I.—*Daily allowance to each man.* (*Salt provision.*)

		oz. carbon.
16 oz. biscuit, at 41 per cent. carbon .	=	6·56
12 " salt meat, at 20 per cent. carbon .	=	2·40

12 oz.	flour at	40 per cent. carbon		. .	=	4·80
1 "	cocoa	70	"	"	=	·70
1·5 "	sugar	42	"	"	=	·63
						15·09

Or 13·75 ounces troy.

Table II.—*Daily allowance to each man.* (*Fresh provisions.*)

						oz. carbon.
16 oz.	biscuit, at 41 per cent. carbon			.	=	6·56
16 "	fresh meat at 15 per cent. carbon				=	2·40
1 "	cocoa	70	"	" .	=	·70
1·5 "	sugar	42	"	" .	=	·63
8 "	vegetables				=	·80
						11·09

Or 10·1 ounces troy.

If we are content to assume, with Liebig, that the small quantity of carbon found in the excretions is compensated by that contained in the beer or spirits, and other trifling articles furnished to the men, but omitted in the table, then the numbers will really represent the amount employed in respiration.

On the whole, it seems probable that this method of experiment, carefully followed, will give more trustworthy results than the first described; it is no doubt both laborious and disagreeable, but its value is great.

M. M. Andral and Gavarret* have very recently published a series of interesting experiments on the same subject, not yet, however, complete, in which they seek to establish the influence of age, sex, and other circumstances, upon the production of carbonic acid by respiration. The maximum quantity of

* Ann. Chim. et Phys., 3d series, viii., p. 129.

carbon exhaled by a young and healthy man, is stated at about 217 grains per hour, or 13 ounces troy daily.

The preceding brief notice of the general nature of animal nutrition, will, it is hoped, put the reader into a position to consider with advantage certain remarkable cases of the special adaptation of the chemical nature of the food to the circumstances of the individual for whose use it is designed.

The bodily frame and constitution of the human race have been so adjusted as to admit of the maintenance of life and health under a variety of circumstances truly surprising. Extremes of heat and cold, of moisture and dryness, are borne with impunity so long as the habits and mode of life of the individual remain in accordance with his physical condition.

In tropical countries where the high temperature of the air, and the abundance of aqueous vapour it contains, develop to the utmost the resources of vegetable life, the amount of personal labour required for self-support is extremely trifling. The heavy and laborious culture of the temperate regions, the unceasing tillage of the soil, so necessary with us, are altogether uncalled for. In those smiling regions of almost perpetual sunshine, where the teeming earth gives its increase with the least possible toil on the part of the cultivator, and all Nature invites to repose and indolence, the energies of the mind itself are unstrung by the removal of that sharp spur of necessity which goads men to the task of labour, until exertion becomes a habit, which carries them onward beyond their immediate wants, and impels

them to seek the permanent improvement and exaltation of their state. The sustenance furnished to the human race by a wise and bountiful Providence has been so adjusted, *chemically*, to this condition of things, as involuntarily to excite in the observer the deepest feelings of admiration and gratitude.

Where the temperature of the air approaches within a few degrees that of the body, the generation of animal heat by the burning of organic matter in the blood may be reduced in amount. Where muscular power and motion are less required and less employed, the waste of the body is diminished in the same ratio; a comparatively small quantity of food, both for fuel and for nutriment, is, in such a case, required. The stomach, however, must be filled, the uneasy sensation of want must be removed; and this has been done. In the rice, and fruits, and other products of the countries in question, we find a food extremely agreeable to the taste, but possessing little sustaining power; much of it is mere water, and the solid portion itself is chiefly made up of neutral non-azotized bodies, containing oxygen and hydrogen in the proportions to form water; bodies which, in burning, furnish far less heat than those in which carbon and hydrogen greatly predominate. The azotized portion of the food of hot countries is always very small in comparison with the rest; it is, however, sufficient for the purpose of repairing the trifling daily loss the body sustains. The desire for animal food is very slight, and often is altogether absent.

The North American hunter lives wholly upon

flesh; he patiently follows the footmarks of his game through the wild woods for days together, until he finds an opportunity of surprising it; fasting meanwhile, or, at best, subsisting on a few scraps of dried meat; rivalling the beast of prey in his power of endurance—in his quick, yet stealthy step, and in the searching glance of his eye; careless alike of frost and heat, sleeping on the bare ground, a thin blanket or a buffalo-robe his only protection. It is his food which enables him to do and to suffer all this:—to bear exertions which would destroy him were he not supported from within by a kind of nourishment so concentrated in its form as to supply abundantly during the period of repose, the losses of bodily substance, the deficiencies occasioned by change of matter; and even to render the exertions themselves, violent and continued as they are, actually sources of pleasure.

It is not by any peculiarity of physical constitution that the Indian is enabled to bear hardship, and fatigue, and privation, which to us appear extraordinary; the European, under similar circumstances, and *under a similar regimen*, exhibits the same remarkable powers. The hunters and trappers, employed by the fur companies of British America, lead a still harder life. These men are, as is well known, accustomed to disperse themselves, often singly, along the rivers and streams, the haunts of the beavers and other animals they seek to capture; a rifle, and flint and steel their only household goods, without shelter in the midst of a trackless wilderness, often suffering the extremities of cold and hun-

ger, subsisting entirely on the flesh of the creatures they succeed in taking, and this for months together, until each has collected the number of skins he deems sufficient to repay his labour, or the fast-falling snows of approaching winter drive him to seek the protection of the trader's fort.

And yet this wild existence is said to possess a charm of its own, powerful enough to bind, to the end of their days, those who have once practised it; the unbroken solitude of the lake and the river, the freedom of the desert, and even the very dangers of the pursuit, have their own peculiar attraction. The men themselves, when not cut off prematurely by starvation, or any other of the common accidents of this life, or murdered by the Indians whose vengeance they have provoked by their aggressions, live to old age, exempt from a host of sorrows and afflictions known to a more luxurious race, and perhaps, on the whole, enjoy as much real happiness as commonly falls to the lot of man.

Take, again, the condition of the Esquimaux, in his hut of ice-blocks or driftwood, his only food the seal and the walrus, which he spears with his bone-pointed weapon, from a little frail coracle of skins. The air is cold enough to freeze quicksilver; he wraps himself in his dress of furs, and forth he goes with perfect impunity, and the cold of the shore of the frozen sea affects him less than that of a chilly January day does the Englishman by his warm fireside. Yet the Esquimaux has no fireside; he cooks his food by the heat of a lamp fed with oil, the product of the chase; his country produces no fuel, and

he cannot think of devoting the few fragments of wood, brought by the ocean currents from more favoured climes, which he finds upon the sea beach, to this purpose; they are far too valuable to be so employed. How, then, it may be asked, is he capable of supporting this intensity of cold? the peculiarity of his food furnishes the reply.

We are accustomed to look with horror and disgust at the food of these poor people, as we in our ignorance and presumption dare to call them; to commiserate the taste of those who, as our northern navigators relate, prefer a piece of tallow candle, or a draught of train-oil, to the fare of an English man-of-war; but a little more consideration might, perhaps, show us that the blubber and fat of the arctic cetacea and fish, the only food the inhabitants of these countries can obtain, really constitute the only sort of food which could enable them to bear up against the extremities of cold to which they are subject. There is no other substance but fat, and that in very large quantity, which would answer the purpose required; it is a substance exceedingly rich in hydrogen, and in the body eminently combustible; weight for weight, it will generate a far larger amount of heat, when burned in the blood, than any thing else which can be taken as food. It will be wiser, then, instead of condemning, as filthy and abhorrent, the tastes and propensities of the Esquimaux, to consider them as a special adaptation, by an unspeakably benevolent Providence, of the very wishes and inclinations of the individual to the circumstances of his life.

But this is not all; the same individual, who, when in a warm or temperate climate, craves a large proportion of bread and vegetable food, and turns with aversion from fatty substances, experiences, when transported to the frozen regions of the north, a complete revolution in his tastes and desires. Nothing will then satisfy him but fat;—the flesh of deer, fish, to be acceptable, must be loaded with fat; he takes delight in sucking the marrow from the bones; nothing in the shape of grease comes amiss to him; he longs for it, he desires it as much as he formerly loathed it. But this new, this induced state, only lasts as long as his mode of life requires; removal to a milder region restores, to a very great extent, the first condition.

This is no imaginary statement; it is perfectly authentic, and serves to place in a novel and striking point of view the power of accommodation to circumstances possessed by man.

The very occupations which the people of excessively cold countries are compelled to follow, are connected, in the most intimate manner, with the nature of their food. They are invariably such as to require great bodily exertion. Now this is always attended by increased respiration—the breathing is deeper and much more frequent; and again, from the superior density of the cold air, a larger weight is at each inspiration taken into the lungs; more oxygen is thus carried into the system, the fuel-food is rapidly consumed, and animal heat is rapidly evolved. It is not enough that the furnace-bars be piled with fuel, unless means exist for in-

creasing the supply of oxygen for its combustion; and this is done by compelling the person to occupy himself with the chase of wild animals, instead of following the more staid and quiet life of a herdsman or a tiller of the soil.

In the nutriment which has been provided for the young of the human race, and of the higher classes of animals, we have the most perfect type of food in general that it is possible to give. Provision for this helpless condition of life has been made with the most tender care; the finding of suitable food has not been left to chance, but a supply has been provided, of a kind and in a manner to impress alike upon the giver and the recipient a placid enjoyment of happiness, perhaps not surpassed by any thing on earth, and calculated at the same time, from its very peculiar chemical nature, to afford every principle required for the development of the body of the little one for whom it is destined.

The reader will find, in the appendix, a detailed account of the composition of milk, so far as it is at present known; there are one or two points which yet require to be elucidated, but enough is apparent to indicate how eminently it is fitted for the object to be fulfilled.

It will be seen that the characteristic and leading constituent of milk, casein, is present in large quantity, and in a soluble state; now this casein is identical in composition with the muscular substance, and with the albumen of the blood. It is easy to see its use. By a molecular change, of the simplest kind, it becomes the material of flesh, or passes into

cellular tissue and membrane, by an act of oxidation. We find, besides, associated with this casein, a large quantity of earthy phosphates, held in solution in a very extraordinary manner, in a neutral, or even slightly alkaline menstruum, and which evidently offer the greatest facilities to a most important process at this period of life in great activity, that of the formation of bone. Neither have the elements of respiration been neglected; in childhood, this function is exceedingly energetic, and accordingly no less than two non-azotized bodies have been provided for this purpose, and both upon a very liberal scale—butter and sugar of milk; these burn in the body to carbonic acid and water, and develop the necessary heat. The saline constituents of milk, even the trace of ferruginous matter it contains, are equally useful, although less conspicuous; nothing superfluous is to be found, and nothing essential to the well-being of the infant has been omitted.

Much good would ensue if these simple and rational views of the nature and functions of food were carried out into general practice; how often do we see the evident dictates of nature perverted and set aside in favour of customs and habits prejudicial in the highest degree!

ON

THE RELATION BETWEEN PLANTS AND ANIMALS.

Relations of the most intimate kind link together the two great classes of organized beings; between the vegetable and the animal kingdoms a bond of mutual dependence may be traced exceedingly interesting to contemplate. Although the general nature of the relations may be, in great part, inferred from statements already made, it will be proper to collect and reconsider them before terminating the whole subject.

The food of plants is entirely inorganic; carbonic acid, water, ammonia, and certain salts of metallic oxides, are, so far as we know at present, the only substances capable of being employed by them as food. When other bodies—such as decaying organic matter—seem to be efficacious in this respect, they are so only from their property of easily undergoing changes which end in the production of the bodies mentioned. Vegetables have the power of decomposing these exceedingly stable compounds, and rearranging their elements in such a way as to generate bodies so complex in constitution that they often

baffle our endeavours to represent them and their reactions by exact chemical formulæ. It is by a process of de-oxidation, in the first instance, that these things are brought about—a process which we do not understand, and cannot imitate. The production of albumen or sugar in a plant is at present a complete chemical mystery, which we have not yet been able to penetrate; perhaps we never may, but the fact is not the less certain.

Animals are exclusively nourished by matters already organized; matters which are, as already stated, often identical in composition with the substance of their bodies, or at least always capable of becoming so by chemical changes of a simple and intelligible nature, the analogs of those we are in the habit of producing at will in the laboratory. The animal body is constantly in a state of decay from the chemical action of the oxygen introduced in respiration. The products of this decay are, at first, employed in the system, in various ways, as their nature permits, and, after passing through many successive stages of decomposition, are finally rejected from the body in the form of carbonic acid, and water, and urea—a substance allied to, and readily becoming, carbonate of ammonia.

No contrast can be greater than that presented by the chemistry of vegetable and of animal life. In the one case we have a set of changes occult and refined in the highest degree, incomprehensible in their nature although evident in their effects, the result of which is the production of organic matter out of inorganic; in the other, we have these same or-

ganic substances gradually passing by a descending scale into compounds less and less complex, by changes which we can in most instances understand, and in some imitate, until they at length reach the inorganic condition, and once more become capable of assimilation by plants. A perpetual and unbroken chain of vital phenomena is thus established, the products of the one order of beings becoming the sustenance of the other.

A recent French writer has contrasted these opposite functions of plants and animals in a very pleasing manner.*

THE VEGETABLE	THE ANIMAL
Produces the neutral azotized substances,	Consumes the neutral azotized substances,
——————— fatty substances,	——————— fatty substances,
——— sugar, starch, and gum,	——— sugar, starch, and gum,
Decomposes carbonic acid,	Produces carbonic acid,
——— water,	——— water,
——— ammoniacal salts,	——— ammoniacal salts,
Disengages oxygen,	Absorbs oxygen,
Absorbs heat and electricity,	Produces heat and electricity,
Is an apparatus of reduction,	Is an apparatus of oxidation,
Is stationary.	Is locomotive.

The removal of carbonic acid from the atmosphere is effected by the agency of plants; there are so many sources of this poisonous gas in constant activity, that, were no means in existence for its withdrawal from the air, the latter would become

* Annales de Chim. et Phys., Dec. 1842.

in the end unfit for respiration. It is true that, on any supposition, a great length of time must elapse before such a state of things would arrive; thousands of years would probably pass before the proportion of carbonic acid had risen to such an extent as to exert a perceptible influence; the atmosphere is so vast, of such immense volume, that an alteration of this kind must occur very slowly. It is difficult, however, to say how small an increase of the gas might prove hurtful to animal existence when its effects were continued, as they necessarily would be, upon many successive generations; it is difficult to estimate the minimum quantity of poison necessary to destroy health and vigour in a creature for a very long period subjected to its influence. Besides, all the arrangements of nature bear the impress of stability upon them; where perturbing causes appear to exist, compensation is sure to be discovered if diligently sought. It would be contrary to the analogy of the whole to imagine that a principle were in operation whose ultimate effect would be to render the earth uninhabitable. Carbonic acid is fatal to all animals; its deleterious powers are not merely exerted on a few—all alike perish when exposed to its action. It may be, and, indeed, very probably is, a part of the great design, that successive races of animals should, in turn, inhabit this earth for a certain period, each perishing after a time, and giving place to another, like wave following wave upon the surface of the sea. Man is but a creature of yesterday; his dwelling-place was once the abode of animals, now only known to

us from their remains entombed in the solid earth, and the time may come when his race shall wither away and disappear, like the ichthyosaurus and the iguanodon of old. The permanence of the life of a race may have as little existence as that of an individual; the destruction of the capability of the earth to support life at all is a very different matter.

The same reasoning leads to doubt the supposition which some have entertained of a gradual diminution in the quantity of carbonic acid contained in the air at an earlier period of the history of the earth, when the plants of the great coal formation lived and flourished. The reason assigned for this idea is found in the great development of their leaves in comparison with their roots; plants, *resembling* the ancient species, are still, however, abundant in the warmer regions of the earth, although the air in those localities is not richer in carbonic acid than it is in Europe.

In whatever light we consider these matters, the argument of benevolent design and contrivance, deduced from the obvious facts themselves, remains unaltered. The care and beneficence of the Creator is not less shown in the connexion he has established between physical and moral health. The labour which a man is obliged to exert to procure for himself the necessaries of life is not less essential to the maintenance of a healthy tone of mind than of a sound and active condition of the bodily organism. That labour should be the lot of the human race, instead of being, as some have represented it, a curse, is, in fact, the highest blessing that could

have been bestowed. No evil can be greater than the rust, alike of body and soul, which results from inactivity. The state of labour is the very condition of enjoyment; not, indeed, the excessive and slavish toil to which a very large portion of mankind have, by a most unfortunate combination of circumstances, been reduced, but that moderate and well-regulated labour of mind and body, which conduces so much to the welfare of both, and which would be, under more favourable auspices, fully sufficient to impart comfort and abundance to all. If men only knew and felt how inseparably their own individual happiness is connected with the welfare and prosperity of their species; if those who have intellect, and power, and wealth at their disposal, could only be persuaded to thrust aside the petty jealousies and cares, the idle parade and prejudices of society, and join heart and hand in the great work of human improvement, how much might be effected! How much happier and how much better all might become if a sound and universal spirit of philanthropy were once awakened, capable of embracing within its pale all orders and conditions of men, considering them, as they really are, the children of one common Parent, bound together by the ties of brotherhood, each having a special duty assigned to him to perform, not independently of, but in conjunction with, the rest, and exciting all to render each other mutual assistance in surmounting the difficulties and trials of this life of discipline and pupilage.

The first and most indispensable condition of happiness to a reflecting, intelligent man, must be

the acquisition of sound, consistent, and cheerful views of the relation in which he stands to his Creator; without these, all external appliances and means are worthless. Unless he be deeply impressed, thoroughly imbued, with the conviction that he is, and shall be, every moment of his existence in the hands of a Being of unmixed and unbounded benevolence, exerted under the guidance of wisdom and knowledge, embracing all possible contingencies, and rendered effective by power extending to all things not involving contradiction, he cannot be permanently happy. It is melancholy to reflect upon the evils which have been brought upon the earth by the adoption of narrow and false ideas of God and of his attributes. The great and beneficent Creator has been invested with the passions and infirmities of humanity. He has been represented as delighting in the exercise of mere arbitrary power; as capricious and revengeful; as exercising a kind of favouritism towards particular individuals, and suffering the rest to remain in a state of hopeless misery. Men have sought, in the figurative language of Scripture, confirmation of these views, and have not scrupled to indulge their own evil nature in persecuting their fellows under the mask of religious zeal. Even those whose sincerity and purity of motive are altogether above suspicion, have been led to the perpetration of acts from which, under other circumstances, they would have recoiled with horror.

The attributes of the Deity have been constantly placed in opposition to each other. Good men have laboured to reconcile justice and mercy, as if they

could ever be at variance! All this arises from a misunderstanding of the general principle of benevolence: from confounding two things essentially distinct—namely, real, provident goodness, and weak, short-sighted indulgence. The true type of God's government is to be found in that exercised by a wise and good parent over his children. He corrects them when necessary by the infliction of pain, and stimulates them to improvement by the hope of pleasure or reward; but the motive is the same in both cases. It is an enlightened, active benevolence which prompts him to punish where punishment is needful. To withhold this would be any thing but an act of mercy. The dealings of God towards man are of this character. We have the positive assurance of One who spake as never man spake, while the analogies of nature, and the silent conviction of our own souls, testify to the truth of this greatest and most important of all doctrines.

It is by such fatal misconceptions that so many worthy and earnest men have been driven into fanaticism on the one hand, or infidelity on the other; —to abandon the light of reason altogether as a most treacherous guide, or to cast away the authority of inspiration, and justify the act by insisting on the repugnancy of its dogmas to the best and noblest feelings of the human heart. What better and more obvious plan can be devised for preventing such deplorable mistakes than that of making the *works* of the Creator the commentary and exponent of his written *word?* May not the light of nature thus employed, by exhibiting in all their generality and

magnificence the great fundamental truths which form the basis of all sound and harmonious religion, become a key to a number of apparent anomalies in Holy Writ, which perplex and harass the mind of the inquirer?

What is the object of all science? Is it to procure the means of increased indulgence and refinement in the luxuries and the arts of life that we seek to extend the boundaries of natural knowledge? Is the discovery of abstract principles only desirable on account of the possible application of these principles to the attainment of wealth and power? It cannot be by any such considerations that the philosopher is urged forward in his painful and thorny path of discovery. It is rather by an irresistible impulse, an instinct of his nature, which prompts him to rejoice in the contemplation of physical truth for its own sake, and to take delight and pleasure in its development. It would be improper to underrate the value to mankind of the thousand beautiful applications of scientific principles to the purposes of daily life, but it is false to assume that these are other than subordinate to the one great object of all—the elevation and improvement of the mind itself. Nowhere throughout the whole creation is the goodness of the Almighty more conspicuous than in the means he has provided for revealing himself to his intelligent creatures, by conferring upon them these very powers of discovering truth, and of appreciating its beauty and loveliness.

APPENDIX.

I.

ON THE EXISTENCE OF PHOSPHORIC ACID IN ROCKS OF IGNEOUS ORIGIN.

The reasons mentioned in the body of the Essay induced the author to suppose that many mineral bodies of volcanic origin might be found to contain traces of phosphoric acid; a substance easily overlooked, unless suspicion of its presence exists, and special search is made for it. The properties of phosphate of alumina so much resemble those of the pure earth, that, unless the experimenter be very much upon his guard, he is very likely to be led into error.

The first substance examined was pure white porcelain clay, the result of the decomposition of felspar, from Dartmoor, Devon. It gave, on analysis by the usual method, in 100 parts—

Silica	47·20
Alumina, with trace of iron and manganese	38·80
Lime	·24
Water	12·
Alkali and loss	1·76
	100.

A quantity of dry clay in powder, amounting to 1000 grains, was boiled several hours in a flask, with dilute hydrochloric acid, mixed with a large volume of distilled water, and allowed to remain at rest until the following day. The clear and highly acid liquid was next decanted from the sediment, evaporated to a small bulk, and super-saturated with pure ammonia. The precipitate, collected on a small filter, washed, dried, carefully separated from the paper, and heated to redness, was next reduced to powder, and intimately mixed with an equal weight of pure silica and six times as much dry carbonate of soda. This mixture was fused in a platinum crucible. When cold, the melted mass was dissolved out with boiling water, and placed upon a filter to separate the insoluble silicate of alumina and oxide of iron. The filtered solution was next rendered acid by nitric acid, evaporated to dryness, treated with water, rendered exactly neutral by a drop or two of ammonia, and again filtered. The solution so obtained, gave, on the addition of nitrate of silver, a beautiful pale yellow precipitate, soluble both in ammonia and acetic acid; and, on being mixed with some hydrochlorate of ammonia and a little excess of caustic ammonia, furnished, with a drop of solution of sulphate of magnesia, an abundant crystalline white precipitate, characteristic of the presence of phosphoric acid.

These results, which were perfectly unequivocal, were obtained again and again; the distilled water and re-agents employed were examined with the utmost care, and every precaution was taken to avoid

an accidental introduction of the substance sought. It will be observed that filtration of acid liquids was always avoided, lest a trace of phosphate should be dissolved from the paper, and the experiment thus vitiated.

A similar portion of the crumbling decomposed granite, from the same locality, on being subjected to the foregoing process, gave distinct evidence of phosphoric acid.

The phosphoric acid is probably in combination with alumina.

Sound and unaltered crystallized pink felspar, from Germany, was reduced to a fine powder in a mortar of Swedish porphyry, and examined by the same method. The result was a failure; the mineral was too hard to be acted upon by dilute acid.

Two hundred grains of the same substance were then fused, in a platinum crucible, with six hundred grains of dry carbonate of soda; the mass treated with water and filtered. The solution, after the silica had been separated, gave but equivocal symptoms of the presence of phosphoric acid.

It is probable that by acting on the powdered mineral with hydrofluoric acid, the phosphoric acid may be found in the unchanged felspar as readily as in the decomposed mineral. The want of a platinum retort for preparing the hydrofluoric acid, prevented the experiment.

Dark-coloured vesicular lava from the Rhine, now quarried for the purpose of completing the cathedral of Cologne, powdered in the porphyry mortar, and treated in the same manner as the por-

celain clay, yielded not mere traces of phosphoric acid, but abundance; enough to perform the experiments by which its presence was made known upon a large scale. This is, no doubt, part of the secret of the extraordinary fertility of certain soils derived from the decomposition of lava.

White trachyte, from the Drachenfels, near Bonn, on the Rhine, subjected to a similar method of treatment, gave up a large quantity of phosphoric acid. This rock is chiefly composed of glassy felspar.

Red scoriaceous lava, from Vesuvius, reduced to fine powder and boiled with dilute hydrochloric acid, was acted upon to a considerable extent. The solution contained much phosphoric acid.

It would be worth while repeating the search for this substance, not only in felspar, but in mica and hornblende, using perhaps hydrofluoric acid to disintegrate the minerals. When a very large mass of salt is present, as in the unsuccessful experiment before described, the trace of phosphate escapes detection.

II.

ON THE RELATIONS OF GRAPE-SUGAR, MILK-SUGAR, ALCOHOL, AND LACTIC ACID.

The very general use of chemical formulæ, and their adoption into every elementary work on the subject, induce the hope that the symbolical language almost of necessity made use of in this part of the volume, will be intelligible. The equation

is such a convenient mode of representing chemical changes and relations of composition, and tends so much to brevity and clearness, that its advantages are acknowledged by all.

It will be merely necessary to remind the reader that the letters C, H, O, N, &c., indicate *equivalents* of carbon, hydrogen, oxygen, and nitrogen, the number of which is pointed out by the small appended figure. When the letter alone is used, *one* equivalent is meant.

(*a.*)—Vinous fermentation.

Grape-sugar, $C_{12}H_{14}O_{14}$	2 equiv. alcohol . .	$C_8H_{12}O_4$
	4 equiv. carb. acid .	C_4O_8
	2 equiv. water . .	H_2O_2
		$C_{12}H_{14}O_{14}$

(*b.*)—Conversion of milk-sugar into lactic acid.

Crystallized milk-sugar, $C_{12}H_{12}O_{12}$	2 equiv. lactic acid .	$C_{12}H_{10}O_{10}$
	2 equiv. water . .	H_2O_2
		$C_{12}H_{12}O_{12}$

The mode of conversion of grape-sugar into lactic acid will be obvious from the foregoing. It is stated that cane-sugar cannot itself ferment, and that, when this seems to occur, it is always by first passing into the state of grape-sugar.

III.

COMPOSITION OF ALBUMEN, FIBRIN, AND CASEIN, FROM THE ANIMAL BODY.

The analyses of Mulder are quoted from the *Lehrbuch* of Berzelius, and those of Dr. Scherer from his paper in the *Annalen der Chemie und Pharmacie*, vol. xxxix. The memoirs of M. Dumas is to be found in the December number of the *Annales de Chimie et de Physique*, 1842.

(*a.*)—Albumen.

	MULDER.	SCHERER. From eggs.	SCHERER. From serum.
Carbon	54·84	55·000	55·097
Hydrogen	7·09	7·073	6·880
Nitrogen	15·83	15·920	15·948
Oxygen	21·23	22·007	22·075
Phosphorus	·33		
Sulphur	·64		
	100·	100·	100·

The following are the mean results of two sets of experiments by Dumas:—

	From human serum.	From eggs.
Carbon	53·32	53·37
Hydrogen	7·29	7·10
Nitrogen	15·70	15·77
Oxygen	23·69	23·76
	100·	100·

(*b.*)—Fibrin.

	MULDER.	SCHERER.		
Carbon	54·56	54·454	55·002	54·976
Hydrogen	6·90	7·069	7·216	6·867
Nitrogen	15·72	15·762	15·817	15·913
Oxygen	22·13	22·715	21·965	22·244
Phosphorus	·33			
Sulphur	·36			
	100·	100·	100·	100·

Dumas gives, as the composition of human fibrin—

Carbon	52·78
Hydrogen	6·96
Nitrogen	16·78
Oxygen, sulphur, and phosphorus	23·48
	100·

(*c.*)—Casein.

	MULDER.	SCHERER.		
Carbon	54·96	54·721	54·665	54·580
Hydrogen	7·15	7·239	7·465	7·352
Nitrogen	15·80	15·724	15·724	15·699
Oxygen	21·73	22·316	22·146	22·372
Sulphur	.36			
	100·	100·	100·	100·

According to Dumas, on the contrary, casein of cow's milk contains—

Carbon	53·50
Hydrogen	7·05
Nitrogen	15·77
Oxygen and sulphur	23·68
	100·

(*d.*)—Protein.

The following are Mulder's results :—

	From vegetable albumen.	From fibrin.	From albumen.	From casein.
Carbon	54·99	55 44	55·30	55.159
Hydrogen	6·87	6·95	6·94	7·176
Nitrogen	15 66	16·05	16·02	15·857
Oxygen	22 48	21·56	21·74	21·808
	100·	100·	100·	100·

Dr. Scherer's experiments afforded—

	From crystalline lens.	From albumen.	From fibrin.
Carbon	55·300	55·160	54·848
Hydrogen	6·940	7·055	6·959
Nitrogen	16·216	15·966	15·847
Oxygen	21·544	21·819	22·346
	100·	100·	100·

Dumas gives—

	From casein.	From albumen.
Carbon	54·36	54·38
Hydrogen	7·10	7·14
Nitrogen	15·94	15·92
Oxygen	22·60	22·56
	100·	100·

The results of the analyses of MM. Mulder and Scherer will be seen to coincide in a manner wonderfully complete when the difficulties attending such experiments are taken into consideration. M. Dumas will hardly be justified in applying to the evidently careful researches of Dr. Scherer the term,—"Analyses executées avec une fâcheuse précipitation et tout-à-fait incorrectes." The subject must still be considered open to investigation.

IV.

COMPOSITION OF ALBUMEN, FIBRIN, AND CASEIN, FROM THE VEGETABLE KINGDOM.

Fibrin, from Wheaten Flour.—(Dr. Bence Jones.*)

Carbon	53·83
Hydrogen	7·02
Nitrogen	15·58
Oxygen, sulphur, and phosphorus	23·57
	100·

Protein, from the foregoing.—(Dr. Scherer.†)

	I.		II.
Carbon	54·663	...	54·617
Hydrogen	7·302	...	7·491
Nitrogen	15·810	...	15.809
Oxygen	22·285	...	22·083
	100·		100·

Vegetable Casein.

	DR. SCHERER.‡		DR. BENCE JONES.§
Carbon	54·138	...	55·05
Hydrogen	7·156	...	7·59
Nitrogen	15·672	...	15·89
Oxygen and sulphur	23·034	...	21·47
	100·		100·

Vegetable Albumen.—(Dr. Jones.‖)

Carbon	54·74
Hydrogen	7·77
Nitrogen	15·85
Oxygen, &c.	21·64
	100·

* Annalen der Chemie und Pharmacie, 40, p. 65.
† Idem, 40, p. 7. ‡ Idem, 40, p. 8.
§ Idem, 40, p. 67. ‖ Idem, 40, p. 66.

V.

COMPOSITION OF THE BLOOD.

The following statement of the composition of healthy human blood will serve to convey to the reader an idea of the relative proportions of its components. Such analyses are useful, although it must be observed that they can only be considered as rudely approximative, from the practical difficulties of the inquiry. It is on the authority of M. Lecanu.—(*Annales de Chimie et de Physique*, xlviii. 320.)

Water	780·145 ...	785·590
Fibrin	2·100 ...	3·565
Albumen	65·090 ...	69·415
Colouring matter	133·000 ...	119.626
Crystallizable fat	2·430 ...	4·300
Oily fat	1·310 ...	2·270
"Extractive," soluble in water and alcohol	1·790 ...	1·920
Albumen, in union with soda	1·265 ...	2·010
Chlorides of sodium and potassium; alkaline carbonates, phosphates, and sulphates	8·370 ...	7·304
Carbonates and phosphates of lime, magnesia, and iron	2·100 ...	1·414
Loss	2·400 ...	2·586
	1000·	1000·

The earthy and alkaline carbonates mentioned in the analyses probably exist in the state of organic salts in the blood.

The ultimate composition of blood, *as a whole*, is curious. It is precisely the same as that of mus-

cular flesh. Ox-blood was dried by exposure to gentle warmth in a silver vessel, and compared by analysis with the lean flesh of the same animal also carefully dried.*

	Blood in 100 parts.		Muscle in 100 parts.
Carbon . . .	51·950 — 51·965	. . .	51·83 — 51·893
Hydrogen . .	7·165 — 7·330	. . .	7·56 — 7·590
Nitrogen . .	17·172 — 17·173	. . .	17·15 — 17·160
Oxygen, &c. .	19·295 — 19·115	. . .	19·23 — 19·127
Ashes . . .	4·418 — 4.413	. . .	4·23 — 4·230

Flesh is, in fact, organized blood; and blood fluid flesh.

VI.

ON THE FORMATION OF GELATINOUS TISSUE.

It becomes us to speak very cautiously respecting the exact nature of the change by which the protein compounds are made, by an act of oxidation in the body, to yield the gelatinous tissues; which latter, in all probability, have the same composition as the gelatin they give when boiled in water, or only differ, at least, in the elements of water. The simplest formula for protein is, according to Mulder, $C_{40} H_{31} N_5 O_{12}$; and that of gelatin, on the same authority, $C_{13} H_{10} N_2 O_5$. Doubling these last numbers, and supposing thirty-four equivalents of oxygen to be consumed in the process, we may venture to represent, by the following equation, what may be *supposed* to take place. The ammonia probably takes the form of urea.

* Drs. Playfair and Boeckmann. See Liebig and Poggendorf's *Handwörterbuch der Chemie*, art. "*Blut.*"

$$\left.\begin{array}{ll}\text{Protein} & C_{40}H_{31}N_{5}O_{12}\\ +34\text{ eq. oxygen} & O_{34}\\ \hline & C_{40}H_{31}N_{5}O_{46}\end{array}\right\}=\left\{\begin{array}{ll}\text{Gelatin . . .} & C_{26}H_{20}N_{4}O_{10}\\ 1\text{ eq. ammonia} & H_{3}N\\ 14\text{ eq. carb. acid} & C_{14}O_{28}\\ 8\text{ eq. water .} & H_{8}O_{8}\\ \hline & C_{40}H_{31}N_{5}O_{46}\end{array}\right.$$

VII.

ON THE GENERATION AND USE OF FAT IN THE ANIMAL SYSTEM.

The non-azotized constituents of the food, employed in man and the herbivora, and, to a smaller extent, in the flesh-eating animals, in the generation of heat in the body, are of two kinds,—namele, fatty substances, and neutral principles containing oxygen and hydrogen in the proportions to form water. The use of these latter is, of course, exclusively confined to the vegetable feeders.

That the fat which has actually been deposited in the body from its superabundance in the blood, can be again re-absorbed and disappear from the system, is a truth too obvious to need discussion; and that this disappearance is due to the act of respiration, is amply evidenced by the state in which the elements of the substance issue from the body—namely, that of carbonic acid and water. It is also a thing of common observation, that the amount of bodily exercise taken by the animal influences to a very great extent the secretion of fat, which is promoted by rest and inactivity, and hin-

dered by all causes which exalt the respiratory function, or depress the nervous system.

A much more difficult question is that of the origin of the animal fatty principles. In the first place, it is to be remarked that, taken as a class, the bodies of carnivorous animals are much more deficient in fat than those of the vegetable feeders, in which it often abounds, as we well know, to a great extent. Now, there are obviously but two modes by which the occurrence of this substance can be explained—namely, to imagine that it has been introduced ready formed by the food, or that it has been generated in the body itself out of some other substance so introduced. The first of these opinions is held by the French school; the second is that of Professor Liebig, who assigns to the starchy and saccharine portions of the food of the graminivora, *which remain in excess after the performance of the respiratory function*, the duty of actually producing fat by undergoing a change, the analog of the vinous fermentation.

In support of this opinion, a number of facts, well known to agriculturists and graziers, are brought forward to prove the power possessed by amylaceous food in the economical fattening of cattle and other animals, which appear, at first sight, to furnish evidence of the most conclusive nature in favour of the view held by the great German chemist.

On the other hand, it is alleged that all vegetable substances usually employed for food contain fatty matters, which can be extracted from them by

suitable means, and this to a very far greater extent than has hitherto been admitted; to an extent, in short, fully sufficient to account for the presence of all the fat found in the body of the animal after death, or separated from it in the milk-secretion during life.

It is with this inquiry, as with many others of far greater importance to the world at large:—a question which at first appears extremely easy to solve, frequently assumes during the progress of the investigation an air of far greater complexity than we were prepared to expect. Things taken for granted in the first instance, as well known matters of fact, begin to be called in question. Proof is demanded of the veracity of propositions of old and established standing, and the inquirer often finds himself compelled to begin *de novo*, and build up his argument with materials drawn from his own resources of experiment or observation.

We knew of old that *traces* of fatty substances were to be found in, perhaps, all vegetable products, but we were hardly prepared to meet with them to so great an extent in the common food of the domestic animals, as the experiments of MM. Dumas, Boussingault, and Payen indicate.* The following are some of the most curious of their results:—

Vegetables.	Fat in 100 parts.
Maize, as a whole	8·75
Rice	1·

* See Annales de Chimie et de Physique, vol. viii. p. 63. Third Series.

Oats	3·3
African Wheat	2·1
Venezuela wheat	2·6
Fine wheat flour	1·4
Bran from the same	4·65
Dry hay	3· to 4
Straw of African wheat	3·2
Lucern (dry ?)	3·5
Oat straw	5·1
Tares	2·
Beet-root, moist	·05
Potatoes, moist	·08

If these large numbers really represent the *average* proportion of fat in the above-mentioned articles of agricultural produce, it may indeed be needless to resort to any hypothesis of the formation of that substance in the body. The whole question evidently turns upon this single point, which, of course, can only be decided by a very extended series of most accurate experiments.

It is proper to observe that the fatty matter contained in plants is very often of a kind resembling wax; and it is rather doubtful how far such a substance can become converted into ordinary fat. A portion certainly passes through the body unchanged. On the other hand, we have as yet no proof that starch or sugar can suffer the alteration before alluded to, either in the body or out of it.

VIII.

ON THE COMPOSITION OF MILK.

The following statement of the composition of

fresh cow-milk is deduced from the recent experiments of Haidlen :* 100 parts contain—

Water	88·3
Casein	4·82
Milk-sugar	3·39
Butter	3·
Phosphate of lime	·231
——— magnesia	·042
——— iron	·007
Chloride Potassium	·144
——— sodium	·024
Soda (in union with casein)	·042
	100·

It is stated by Mulder, and others, who have made casein the subject of their inquiries, that this body, separated by precipitation from milk, contains no unoxidized phosphorus ;—a substance present in both fibrin and albumen. Now, it is very certain that milk alone is fully competent to the nourishment of a young animal; that is to say, to the production of every part of its body, including those which contain phosphorus in the state referred to. Either, therefore, the animal system must have the power of de-oxidizing phosphoric acid—a thing little probable—or some yet unknown source of phosphorus exists in milk which has escaped observation.

It is curious to observe the manner in which the earthy phosphates are held in solution in milk by the joint assistance of the casein and the free alkali. (See the paper just quoted.)

* Annalen der Chemie und Pharmacie, 45, p. 263.

IX.

ON THE ARGUMENT OF DESIGN DEDUCED FROM THE STUDY OF THE LAWS OF CHEMICAL COMBINATION.

It is possible that an argument of great force and value may be based upon the peculiarities of the laws which determine chemical union, without reference to any hypothetical views of the constitution of matter.

The following is a very brief notice of the laws themselves :—

(*a.*) Laws relating to simple combination by weight, four in number.

1. All chemical compounds are definite in their nature, the ratio of the elements being constant.
2. When a body is capable of uniting with a second in several proportions, these proportions bear a simple relation to each other.
3. If a body, A, unite with other bodies, B, C, D, the quantities in which B, C, D, unite with A, represent also the *relations in which they unite among themselves.*
4. The combining quantity of a compound is the sum of the combining quantities of its elements.

A few words of explanation will suffice to render the purport and bearing of these laws intelligible.

The first law is almost self-evident : it is quite natural to expect constancy of composition in the same substance, however produced. The converse of the proposition, however, is very far from being

true, since the *same* elements uniting in the *same* proportions do not necessarily generate the same body. The large class of isomeric compounds are examples of this most interesting fact; for in these we often have the greatest imaginable diversity of character associated with absolute identity of composition. These bodies belong nearly all to organic chemistry, and consequently result from the very peculiar properties of carbon, hydrogen, nitrogen, and oxygen, upon which much stress has been laid.

The second law is very simple, and yet very important; it exhibits a remarkable relation always found to obtain between closely allied compounds of the same substances. The oxides of nitrogen afford an exceedingly beautiful illustration of the rule in its simplest form. These oxides are five in number, and possess the undermentioned composition by weight:

	Nitrogen.		Oxygen.
Nitrous oxide	14·1	...	8
Nitric oxide	14·1	...	16
Nitrous acid	14·1	...	24
Peroxide of nitrogen	14·1	...	32
Nitric acid	14·1	...	40

So that, taking a constant quantity of the one element in each case, the proportions of the other increase by multiples of the first term—8, 8 × 2, 8 × 3, 8 × 4, &c. The same fact is evident in a vast number of other instances: carbonic acid contains exactly twice as much oxygen in proportion to the carbon as carbonic oxide; the red oxide of mercury contains twice as much oxygen as the gray

oxide, &c. Neither is the law limited to elementary substances; it regulates the formation of salts. Of the three oxalates of potash, the second contains twice as much acid as the first, and the third four times as much,—the quantity of the base being equal. It is not always, however, that the relation is so simple as that of one to two, or one to four; two to three is very common; two to seven is sometimes met with, but rarely. Other proportions are occasionally seen, but it is often doubtful whether the substances to which they belong are direct compounds of their constituents. The oxides of iron and manganese furnish instances of the relations mentioned:

OXIDES OF IRON.

	Iron.		Oxygen.
Protoxide .	28	...	8
Sesquioxide	56	...	24
Ferric acid .	28	...	24

OXIDES OF MANGANESE.

	Manganese.		Oxygen.
Protoxide .	27·7	...	8
Sesquioxide	55·4	...	24
Peroxide .	27·7	...	16
Manganic acid	27·7	...	24
Hypermanganic acid .	55.4	...	56

The third law is of the utmost importance. If a substance be taken whose range of affinity is very great, and the proportion in which it unites with a number of other bodies accurately determined by experiment, a series of numbers will be obtained which represent the relative capacities of saturation of the bodies concerned. For example: oxygen is a substance amply fulfilling the conditions required; it forms a vast number of combinations, for the most part easy to examine. It is found, on trial, that a

constant quantity of oxygen—say eight parts, by weight—enters into definite chemical union with the other elementary bodies, in such a way as to require of the latter quantities represented by the numbers below, or by numbers bearing a simple relation to them.

Oxygen	8	unites with—
Hydrogen	1	
Carbon	6	
Sulphur	16·1	
Chlorine	35·5	
Iodine	126·3	
Potassium	39·2	
Sodium	23·3	
Iron	28·	
Copper	31·6	
Silver	108·	
Lead	103·6	
&c. &c.		

The numbers thus obtained are termed "equivalent," for the very obvious reason that they are the representatives of quantities of matter capable of exactly replacing each other in combination.

The formation of such lists of chemical equivalents is effected by analysis, by experiment alone; the choice of the substance with which to start, and the quantity of that substance assumed, are alike arbitrary, and are determined by considerations of convenience.

The great point, the essence of the law under discussion, now follows:—it states, that these equivalent numbers not only represent the relative proportions in which the bodies unite with a given

quantity of the substance at the head of the column, but also the *proportions in which they unite among themselves* whenever combination occurs.

Thus, in the case cited, when hydrogen and iodine combine, it is in the ratio of 1 to 126·3; when iron and iodine unite together, we have 28 parts of the former to 126·3 parts of the latter; 23·3 parts sodium, or 39·2 parts potassium combine with 35·5 parts chlorine, or 126·3 parts iodine, or 16·1 parts sulphur, &c. &c. It is impossible to overestimate the importance of this law, when followed into its consequences.

The fourth law is also quite independent of the rest, and is also based upon purely experimental proof.

No reason can be assigned beforehand, that the combining number of the compound body shall be exactly the sum of the combining numbers of its components. The assumed equivalent of sulphuric acid is 40·1, being made up of one equivalent of sulphur and three equivalents of oxygen. Now, on trying how much potash or soda these 40·1 parts of sulphuric acid will saturate, it is found that of the first 47·2 parts, and of the second 31·3 parts are required to form a neutral combination; but these numbers respectively contain the *equivalents of potassium and sodium added to that of oxygen*, or, in other words, the equivalents of the compounds are made up of the equivalents of their constituents.

Apart from purely hypothetical considerations, no possible reason can be given why 40·1 parts of acid should exactly require for neutralization the

quantities of base mentioned. It is found by experiment to do so; but it was a result that, however it might have been guessed at, could not have been foreseen.

Among these four separate and independent laws, which, be it ever remembered, rest entirely upon experimental proof, and are altogether unconnected with theory or hypothesis of any kind, relations may be traced important and interesting in the highest degree. It is to the peculiar nature of these relations, and of the laws which they thus link together, that we must attribute the wonderful facility with which combinations of all kinds are produced, each definite and invariable in its nature, and also the ease with which we are enabled to push our investigations in this department of science; they furnish us with checks and methods of control which are perfectly invaluable, and aid to reduce within exceedingly narrow limits the inevitable errors of experimental inquiry.

(*b.*) A very curious relation is found also to exist between the combining quantity of a substance, and its volume, or measure, in the gaseous state. We find that—

8	grains of oxygen, at 60° F. and 30 inches bar., occupy	. . . .	23·5 cubic inches.
1	— hydrogen	. . . .	46·8
35·5	— chlorine	. . . .	46·5
126·3	— iodine vapour	. . . . . .	46·7

It is easy to make this calculation from a knowledge of the specific gravities of the bodies.

Now, on examining the second column in the

above table, it will be seen that the last three numbers coincide so closely that they may be taken as identical, and that the first is as nearly one-half. But the weights are very different indeed—they are very remarkable—*they are no other than the equivalent numbers.*

We have in these peculiar relations of density a most beautiful explanation of the fact, discovered many years since by M. Gay-Lussac, that when gaseous bodies combine it is always either in equal volumes, or in volumes bearing to each other a simple relation; and it is easy to see why it must be so. Equal measures of chlorine and hydrogen, for example, combine to form hydrochloric acid gas; these equal measures contain quantities of matter in the proportion, by weight, of 35·5 to 1, or in the ratio of the equivalent numbers. A volume of oxygen unites with two volumes of hydrogen, because these quantities are to each other, by weight, in the relation of 8 to 1. This rule extends to compounds of every description as well as to elementary bodies, and indeed embraces every substance capable of existing in the gaseous condition.

It is difficult to avoid the conclusion, that these exquisitely beautiful laws and relations have been framed and adjusted to each other by an intelligent mind.

THE END.

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